

Report SAM-TR-80-6

**LEVEL II**

②  
B.S.

**THERMAL CONDITIONS IN THE COCKPITS OF USAF AIRCRAFT:  
INFLIGHT MEASUREMENTS FROM THE A-7, A-10, F-4, F-15,  
AND YC-14**

Richard F. Stribley, Captain, USAF, BSC

ADA087273

DTIC  
ELECTE  
JUL 30 1980  
S D E

April 1980

Interim Report for Period June 1977 - December 1978

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE  
Aerospace Medical Division (AFSC)  
Brooks Air Force Base, Texas 78235



80 7 28 148

DDC FILE COPY

## NOTICES

This final report was submitted by personnel of the Crew Protection Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-10-32.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

*Richard F. Stribley*

RICHARD F. STRIBLEY, Captain, USAF, BSC  
Project Scientist

*William J. Sears*

WILLIAM J. SEARS, Col, USAF, BSC  
Chief, Crew Protection Branch

*Roy L. Dehart*

ROY L. DEHART  
Colonel, USAF, MC  
Commander

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 SAM-TR-80-6	2. GOVT ACCESSION NO. AD-AC87 273	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THERMAL CONDITIONS IN THE COCKPIT OF USAF AIRCRAFT: INFLIGHT MEASUREMENTS FROM THE A-7, A-10, F-4, F-15, AND YC-14		5. TYPE OF REPORT & PERIOD COVERED Interim Report Jun 77 - Dec 78
7. AUTHOR(s) 16 Richard F./Stribley Capt, USAF, BSC		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS USAF School of Aerospace Medicine (VNE) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS USAF School of Aerospace Medicine (VNE) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F 7930-10-32
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 11 Apr 1980
		13. NUMBER OF PAGES 73
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Thermal stress Environmental control systems Heat Aircraft		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Cockpit environmental data are presented for A-7, A-10, F-4, F-15, and YC-14 aircraft. Representative values for dry-bulb, dew-point, and black-globe temperatures; air velocity; and four additional air temperatures are presented for each flight. The data are summarized and the physiological implications of the recorded temperatures are discussed. A detailed description of the USAF School of Aerospace Medicine Miniature Environmental Monitor II (MEM II) is provided.		

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

317000

## PREFACE

The author wishes to thank the Commanding Officers of the Joint Test Force, Edwards AFB, California, and the Beeville NAS, Texas, for the use of their bases, aircraft, and personnel to collect the data.

Such a vast amount of data could not have been collected without the help of numerous USAFSAM test personnel. The author wishes to thank Capt R. Ryan and Lt R. Ligday, Special Project Officers for the studies; MSgt M. Tays and SSgt T. Whitley, Instrumentation Specialists and Data Recorders; and MSgt A. Sustaita, who spent many hours reducing the data. A special thank you is extended to Capt R. Hill, JTF, Edwards AFB, California, who acted as liaison officer for these tests and obtained the Class II modifications required for the inflight measurements.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Available/or special
A	

## CONTENTS

	<u>Page</u>
INTRODUCTION . . . . .	5
METHODS. . . . .	5
Location of Investigations . . . . .	5
Aircraft Operations . . . . .	5
Measurements . . . . .	5
Data Collection and Recording. . . . .	7
RESULTS. . . . .	7
A-7D . . . . .	8
A-10 . . . . .	8
F-15 (AECS). . . . .	9
F-15 . . . . .	9
YF-4E. . . . .	9
YC-14. . . . .	9
DISCUSSION . . . . .	10
REFERENCES . . . . .	11
APPENDIX A. The USAFSAM MEM-II. . . . .	13
APPENDIX B. Flight Data . . . . .	16

Preceding Page Blank

THERMAL CONDITIONS IN THE COCKPITS OF USAF AIRCRAFT:  
INFLIGHT MEASUREMENTS FROM THE  
A-7, A-10, F-4, F-15, AND YC-14

INTRODUCTION

During the summer of 1977, test teams from the USAF School of Aerospace Medicine (USAFSAM) visited Edwards AFB, California, and Beeville Naval Air Station, Texas, to record the thermal environment in aircraft cockpits during routine and test operations in hot weather. The teams measured inflight temperatures at several cockpit sites, including the Environmental Control System (ECS) cabin inlet ducts. This report describes the measurements made on A-7D, A-10, F-4, F-15, and YC-14 aircraft.

METHODS

Location of Investigations

Except for one F-15, all aircraft operated from Edwards AFB, California, located at approximately  $35^{\circ}\text{N}$ ,  $118^{\circ}\text{W}$ , in the Mojave Desert. The air base is about 701 m (2,300 ft) above sea level and is located on the dried Rogers Lake bed.

Measurements were also obtained from an advanced ECS (AECS) mounted aboard an F-15 test aircraft operated from Beeville NAS, Texas. The air station, located at approximately  $28^{\circ}\text{N}$ ,  $98^{\circ}\text{W}$ , is 58 m (190 ft) above sea level and is in a semitropical environment.

The USAF teams conducted tests at Edwards AFB from 13 July to 11 August and 13 to 27 September 1977. The team visited Beeville NAS during 25 to 31 August 1977.

Aircraft Operations

The aircraft from which the data were collected flew routine operations as well as test missions. Flight profiles included both high- and low-level operations. Sorties included reconnaissance, air-to-air combat maneuvers, and training missions.

Measurements

Cockpit Temperatures--Dry-bulb temperature ( $T_{db}$ ), 5-cm black-globe temperature ( $T_{bg}$ ), dew-point temperature ( $T_{dp}$ ), and air velocity ( $V$ ) were measured at a sensor cluster mounted in the cockpit near the pilot. Four additional dry-bulb temperatures were collected in different areas of the cockpit or ECS. Sensor locations are given in Table 1. Cabin barometric pressure was also recorded.

TABLE 1. LOCATION OF COCKPIT-TEMPERATURE SENSORS

A-7D

- \* SC) Right side ejection rail, 30 cm from pilot's head
- 1) Canopy bow, about 60 cm in front of pilot's forehead
- 2) Inside glare shield, near front instrument panel
- 3) 23 cm from right thigh
- 4) 15 cm from right calf (under well)

A-10

- SC) Right side of canopy swing arm, 30 cm from pilot's head
- 1) Canopy bow, about 60 cm in front of pilot's forehead
- 2) Under glare shield, near climb indicator
- 3) Right rudder well, near knee
- 4) Right ECS inlet duct

F-15 (AECS) and F-15

- SC) Right camera mounts near right shoulder
- 1) Canopy bow or ECS
- 2) Glare shield
- 3) 23 cm from right elbow
- 4) 15 cm from right calf (rudder well)

YF-4E (Rear seat)

- SC) Right canopy rail
- 1) Instrument panel, at eye level 30 cm from head
- 2) 15 cm from right elbow
- 3) 10 cm from right calf (rudder well)
- 4) Right-knee ECS duct

YC-14 (Left seat)

- SC) 107 cm above floor, near left window bulkhead
- 1) Left shoulder, 107 cm above floor
- 2) Right elbow, 43 cm above floor
- 3) Right calf, 30 cm above floor
- 4) ECS duct

\*SC = Sensor cluster

Airfield Climatic Conditions--Dry-bulb and dew-point temperatures, relative humidity, barometric pressure, cloud cover, and wind direction/speed were obtained from the base weather station at takeoff and landing.

Aircrew Input--Subjective comments were gathered postflight, and aircrews recorded times of significant inflight events.

#### Data Collection and Recording

Measurements of the cockpit environment were recorded automatically every 5 seconds during each sortie by the USAFSAM Miniature Environmental Monitor II (MEM II). A description of the instrumentation is given in Appendix A. Figures of the equipment are available elsewhere (3). Data were stored on cassette tapes for later analysis at the USAFSAM's Wang 2200-S microcomputer facilities. Airfield climatic conditions were hand-recorded immediately before and after the tests.

#### RESULTS

The measurements made for each sortie are presented graphically in Appendix B. A test summary precedes each of the figures for each aircraft. Data were gathered every 5 seconds, but for clarity were averaged every minute; these results were plotted. This smoothing reduced some peak air velocity and cockpit barometric-pressure data, but had little effect upon the relatively slow-changing temperature data.

Each figure includes:

1. Significant events such as canopy down time, takeoff time, and flight altitudes.
2.  $T_{db}$  and  $T_{bg}$  at the sensor cluster.
3.  $T_{db}$  at four additional sites, as given in Table 1.
4. Air velocity and barometric pressure.
5. Ground climatic conditions.
6. Aircraft type and the date data were collected.

All data are plotted against local time in hours. Edwards AFB was 7 hours different from Greenwich Mean Time, and Beeville was 5 hours.

Dew-point temperatures have been omitted from the figures because of technical problems. The sensor (Panametrics) proved to be extremely sensitive to dust, aircraft oils, and exhaust fumes and required constant cleaning and calibration. Since on-site calibration proved difficult, the dew-point data in some cases were suspect.

The following sections review the salient features of the data for each aircraft monitored.

#### A-7D (Figs. B-1 to B-4)

Ground climatic conditions were average for this time of year (normal daily maximum (NDM) =  $33^{\circ}\text{C}$ ). The ECS was on auto maximum cold for all flights. The  $T_{db}$  at all locations was independent of ambient air temperatures during the sorties, possibly due to the short time at low level (<1000 m). All air temperatures were well within the military specifications for cockpit cooling ( $21^{\circ}\text{C}$ ) at high altitude. There are some indications (Fig. B-3) that when the aircraft remained at lower levels after takeoff,  $T_{db}$  remained above  $21^{\circ}\text{C}$ , particularly near the calf and thigh. The  $T_{bg}$  averaged  $7^{\circ}\text{C}$  above  $T_{db}$  during most of the flight. The aircrew's subjective impression of the ECS performance during these flights ranged from "no problem" or "good cooling" to "warm at idle power."

#### A-10 (Figs. B-5 to B-8)

Ground climatic conditions were above normal for this time of year (NDM =  $35^{\circ}\text{C}$ ). The ECS was set on auto maximum cold for all flights, and the auxiliary power unit (APU) was not used during ground operations. The aircraft, #669, was the same as used in the 1976 climatic tests at El Centro NAS, California, and Homestead AFB, Florida (2). The ECS had been modified several times, including changes in duct size and routing. For these reasons, the data do not exactly represent operational aircraft.

In all flights, the  $T_{db}$  at the sensor cluster and throughout the cockpit failed to meet the military specifications ( $21^{\circ}\text{C}$ ) for ECS performance. Temperatures near the right calf averaged the coolest but still were above the  $21^{\circ}\text{C}$  maximum permitted. ECS inlet temperatures, which dropped substantially below  $20^{\circ}\text{C}$  on only one flight, appeared to be too high to provide any cooling to the cockpit.

$T_{bg}$  averaged  $2-5^{\circ}\text{C}$  above  $T_{db}$ . This difference, smaller than previously measured, appears to be due to the location of the black globe, in the sensor cluster, which was shaded more than in previous flights (2).

One flight was ground aborted (Fig. B-5), and the canopy was sealed without ECS cooling to measure the temperatures during power-down conditions. Air temperatures in most locations (calf area excluded) quickly jumped  $10^{\circ}\text{C}$ , and at the sensor cluster exceeded  $65^{\circ}\text{C}$  after 40 minutes. Ground climatic conditions were not recorded, but  $T_{db}$  was about  $35^{\circ}\text{C}$ . Aircrew generally characterized the cockpit as "hot" and complained of sweating. During taxi the canopy was up due to limited ground cooling.

The A-10 was designed to operate with the canopy down and the auxiliary power unit on during ground operations. Data gathered on operational aircraft at Davis-Monthan AFB, Arizona, in 1978 and 1979, indicate that when properly operated, the ECS will cool the cockpit to  $27^{\circ}\text{C}$  during ground or air operations with outside air temperatures of  $43^{\circ}\text{C}$  or greater.

#### F-15 (AECS) (Figs. B-9 to B-14)

Ground climatic conditions were average for this time of year (NDM = 34°C). The ECS was an advanced system being evaluated for possible incorporation into USAF aircraft, and the settings were generally maximum cold. ECS performance appeared to be a function of altitude during flight (Figs. B-11 and B-13) and of power setting during ground operations (Figs. B-12 and B-14).  $T_{bg}$  averaged 8°C above  $T_{db}$ , which rarely fell below 33°C during most ground runs and reached 40°C several times at the sensor cluster during low-level flight.

Despite the high temperatures and sweat rates experienced by the test pilot (at 1504 during the 25 Aug 77 flight, he noted thirst as a problem), heat-stress problems were not mentioned during debriefings, which concentrated on avionics cooling and performance. The excessive sweat appears to be due to high humidities and temperatures during flight as well as before flight.

#### F-15 (Figs. B-15 to B-19)

Ground climatic conditions were below normal for this time of year (NDM = 30°C). The ECS was run at maximum cold. The sensor  $T_{db}$  did not exceed 30°C for any portion of a test sortie, including taxi with canopy down.  $T_{db}$  tended to rise toward 27-29°C during preflight taxi, regardless of the outside  $T_{db}$ . ECS duct temperatures ranged from 7 to 10°C during taxi and apparently supplied sufficient air flow to cool the cockpit, even with full radiant heating.  $T_{bg}$  averaged 7°C greater than  $T_{db}$  at the sensor cluster. The aircrews did not complain of any heat-stress problems. Comparison of these flights to the AECS test flights of the last section is complicated by the difference in ambient  $T_{db}$ , relative humidity, and solar angle.

#### YF-4E (Fig. B-20)

Ground climatic conditions were average for this time of year (NDM = 28°C). The ECS was set at maximum cold. The sensor  $T_{db}$  reached a maximum of 36°C just before takeoff and during the landing pattern. Despite an extremely cold ECS inlet temperature (-4°C),  $T_{db}$  at the sensor cluster did not decrease significantly except during weapon runs. In contrast,  $T_{db}$  at the elbow and calf more closely followed the ECS outlet temperatures, dropping to 5 and -2°C respectively.  $T_{bg}$  averaged 8°C higher than  $T_{db}$  at the sensor cluster. The aircrew did not note any heat-stress problems during the flight.

During taxi, the F-4 canopy was closed just before takeoff. In this short time, cockpit air temperature rose about 6°C. Data from other flights confirm that  $T_{db}$  in the cockpit can quickly exceed 45°C (4).

#### YC-14 (Figs. B-21 to B-24)

Ground climatic conditions were above normal for the time of year (NDM = 34°C). Sensor cluster  $T_{db}$  varied widely with the segment of mission flown, and depended more on the ECS temperature than did the  $T_{db}$  at calf, elbow, or shoulders. ECS temperature during climb to altitude dropped rapidly below 0°C, returning to about 10°C during level flight. The

differences between  $T_{db}$  and  $T_{bg}$  at the sensor cluster were minimal, reflecting the position of the cluster and the response lag of the black globe.

## DISCUSSION

Present military ECS specifications state that cockpit  $T_{db}$  may not exceed  $27^{\circ}\text{C}$  during ground operations. During flight, mean air temperature in the crew compartment should not exceed  $21^{\circ}\text{C}$ , but may rise to  $27^{\circ}\text{C}$  for 30-min periods. Radiant heat is mentioned only in terms of surface temperature and touch-burn, and moisture control is covered by the statement that inlet air shall be free of entrained moisture.  $T_{db}$  measurement sites are left to the discretion of the evaluation team, as is the definition of mean air temperature. Since cockpit cooling is provided for the aircrew as well as for instrumentation, the evaluation of air temperatures and other environmental factors should be performed around the area of interest--in this instance, the aircrew.

Until the construction of the MEM II, USAFSAM was unable to measure inflight air temperature at more than one cockpit location. As shown in the Appendix B figures,  $T_{db}$  at the sensor cluster is generally higher than the air temperatures measured in the rudder well and near the hip or elbow--especially in the A-10 and F-4 aircraft. The pitfalls of single-point cockpit environmental measurements were shown in later tests aboard F-4 aircraft (1).

Multisite temperature measurements used in this study allow better definition of the subject aircraft environment. For example, when the A-7D is operated at altitudes between 3800 and 9150 m, the ECS (Figs. B-1 to B-4) meets or exceeds the present specifications,  $21^{\circ}\text{C}$  while in flight, at all locations. In contrast, the A-10 and YF-4E (Figs. B-5 to B-8 and B-20) fail to meet specifications at one or more measurement sites.

The data from these flights indicate that thermal gradients are present in the cockpit. The A-10 and F-4 in particular have large differences in  $T_{db}$  from the head to the foot. Because of these temperature differences, a pilot can be uncomfortably hot on the head and upper chest, yet have cold feet. This is particularly true where aircrews are exposed to radiant heating of the upper body (3, 4). Temperature gradients were not evident in the YC-14, a transport aircraft, where radiant heating of the cockpit is not a significant factor. Based upon this study, using mean-air-temperature specifications when testing a fighter/trainer aircraft ECS also appears open to question because of the temperature gradients. Future ECS test specifications should include limits on individual air temperatures as well as on the mean air temperature. For example, based upon recent physiological data, additional cool air will be required for the upper body to reduce the effects of solar radiant heat (4).

Cockpit cooling depends upon numerous factors, including ECS inlet temperature and mass flow. Since the MEM-II does not measure mass flow, the true performance of the ECS is not known. A cold inlet temperature with low flow could result in a hot cockpit, while a higher flow at a warmer temperature could result in a cooler cockpit. New equipment should be designed to include this vital inflight measurement.

#### REFERENCES

1. Allan, J. R., et al. The effect of cockpit temperature gradient on the validity of single-point measurements. Aviat Space Environ Med 50:669-671 (1979).
2. Stribley, R. F., et al. Thermal conditions in the preproduction A-10 cockpit during desert and tropical flights. Aerosp Med Assoc Preprint, pp. 50-51, 1977.
3. Stribley, R. F., and S. A. Nunneley. Physiological requirements for aircraft environmental control systems: Control of heat stress in high-performance aircraft. Am Soc Mech Eng Pamph 78-ENAS-22, 1978.
4. Stribley, R. F., et al. Thermal comparison of front and rear cockpits of the F-4 during low-level flight. Aerosp Med Assoc Preprint, pp. 269-270, 1979.

APPENDIX A. THE USAF SCHOOL OF AEROSPACE MEDICINE MINIATURE  
ENVIRONMENTAL MONITOR II (MEM-II)

INTRODUCTION

The USAF School of Aerospace Medicine has been monitoring the thermal environments of aircraft during ground operations and in flight for the past decade. In initial studies, instruments were hand-held and data were hand-logged. Development of the USAFSAM Airborne Bioenvironmental Research Engineering Package (SABRE Pak) permitted automatic inflight recording of data for later analysis on the ground. The SAFRE Pak also allowed the inflight measurement of physiological variables such as core temperature and heart rate. In 1974, USAFSAM developed the Miniature Environmental Monitor (MEM) which was a self-contained environmental monitoring unit that fitted into the seat pack of aircraft (2). The MEM recorded dry bulb ( $T_{db}$ ), dew point ( $T_{dp}$ ), and 5-cm black globe ( $T_{bg}$ ) temperatures, air velocity ( $V$ ), and cabin barometric pressure ( $P$ ). In 1976, construction was started on a smaller version, known as MEM-II, which was used in collecting the data given here.

CONFIGURATION

The modular design of the MEM-II ensures maximum flexibility in application. The unit can be operated from an aluminum case, seat pack, or map case or the modules can be separated by umbilical cables for remote placement in confined spaces. The unit can operate on aircraft power or on a self-contained power supply that can operate for 8 continuous hours. Up to 16 data channels can be recorded every 5, 10, or 20 seconds on a digital recorder or on an analog recorder in a multiplexed mode. A sensor cluster can be remotely mounted to measure  $T_{db}$ ,  $T_{bg}$ ,  $T_{dp}$ , and  $V$ , in addition to other temperatures.

Electronics Unit--This unit weighs 1100 g and is 5.6 cm high by 13.0 cm wide by 19.2 cm long. It houses the barometer, signal-conditioning circuits, multiplexer, clocks, and tape-control electronics. It also contains a built-in calibration circuit which provides zero and span reference signals to all channels. Switches on the electronic unit include 1) a power on-off switch, 2) a record switch to allow for various sensor configurations, and 3) a sampling-frequency switch for the digital recorder.

Analog Recorder--The unit is a 4-channel cassette tape recorder (Inter Med Craft). It is 5 cm high by 11.4 cm wide by 20.0 cm long and weighs 1284 g. Three channels continuously record voice, ECG, and anemometer. The fourth channel is multiplexed to record 16 additional channels.

Digital Recorder--This recorder (Memodyne Model 221W) weighs 2108 g and is 11.9 cm high by 13.7 cm wide by 18.4 cm long. Sixteen channels of information can be stored on the tape cassette. The conditioned signal is sampled and stored (12 bit) along with the channel number (4 bit) in a format compatible with a Wang 2200S computer.

Battery Supply--Two battery supplies are available. The smaller unit (1828 g, 7.6 cm high by 11.2 cm wide by 13.5 cm long) supplies power for 4 hours of continuous use. The larger supply (2545 g, 11.7 cm high by 10.2 cm wide by 19.0 cm long) supplies power for up to 8 hours. If longer recording times are required, the MEM-II can be placed in a hold mode while batteries are changed.

Digital Monitor Meter--This meter (1539 g, 10.9 cm high by 11.5 cm wide by 10.8 cm long) displays the value of the variables being recorded, enabling the user to check the system. Battery supply voltage can also be monitored. The unit is optional and is rarely used in flight.

Sensor Cluster--The cluster (440 g) senses  $T_{dp}$ ,  $T_{bg}$ ,  $T_{db}$ , and  $V$  at a single site in the aircraft.

Additional Equipment--A separate battery charger is required to recharge each of three subunits: the main batteries, the analog-recorder, and the digital-monitor.

## SENSORS

Air Velocity--Air velocity is measured using a metal-clad probe (Thermo-Systems Model 1366) which is suitable where abrasion and contamination might be a problem. A regulated power source furnishes constant voltage to a bridge circuit where the anemometer probe makes up two parts of the bridge; one leg is for temperature compensation, and the other for air flow. The anemometer output is scaled to a range of 0-5 m/s.

Dry-Bulb Temperature--The dry-bulb temperature is sensed by thermistors (Yellow Springs series 700). Output from the sensor circuit is linear with temperature and is amplified and conditioned for display on the digital meter or recorder. The  $T_{db}$  has a range of 0-100°C.

Black-Globe Temperature--The black-globe sensor uses the same thermistor as the dry-bulb sensor. The thermistor is mounted in the center of a hollow copper sphere 50 mm in diameter, with walls 1.5 mm thick and painted flat black. The theory and significance of black-globe temperature has been covered elsewhere (1, 3). The  $T_{bg}$  output has been scaled between 0 and 100°C.

Dew-Point Temperature--A hygrometer (Panametrics Model 2000) senses  $T_{dp}$  and the sensor's output is linearized for recording or output to the digital monitor. The operating range of the sensor is -40 to 50°C.

Cabin Pressure--The pressure transducer (National Semiconductor Model 1603A), located in the electronics unit, is scaled from 0 to 800 mmHg.

Additional Temperatures--In sampling mode 1 on the digital recorder or analog tape, 11 other temperature channels are available. These channels also use YSI 700 series thermilinear thermistors. The probes (disk, brad, or rectal types) give the user flexibility to measure different environmental or physiological temperatures. The channels have been scaled from 0 to 50°C.

Electrocardiogram--A 3-electrode ECG can be recorded unfiltered in the analog mode.

Voice--One channel of the analog tape recorder allows the subject to voice-record pertinent comments.

#### DATA REDUCTION

The analog reproducer unit provides four channels of strip-chart drive output from the analog cassette tape and has been described elsewhere (1).

Digital data reduction is performed on a Wang 2200S computer, which converts taped data into appropriate units and computes additional data such as mean cockpit temperature and wet bulb temperature. The results are stored on a disk for later analysis and plotting. Data reduction programs are available at the USAFSAM/Crew Technology Division/Crew Protection Branch.

#### REFERENCES

1. Graves, K. W. Globe thermometer evaluation. Am Ind Hyg Assoc J 35:30-40 (1974).
2. James, G. R., et al. Miniature environmental monitor, pp. 1-10. SAM-TR-75-29, Aug 1975.
3. Peters, W. R., et al. Survey of environmental parameter sensors for a personal heat stress monitor. Final Report Contract No. 210-75-0036. Southwest Research Institute, San Antonio, Texas, Mar 1976.

## APPENDIX B. FLIGHT DATA

Figures are arranged by aircraft as follows:

<u>Figure</u>	<u>Aircraft</u>	<u>Dates</u>
B-1 to B-4	A-7D	Jul 77
B-5 to B-8	A-10	Aug 77
B-9 to B-14	F-15 (AECS)	Aug 77
B-15 to B-19	F-15	Sep 77
B-20	YF-4E	Sep 77
B-21 to B-24	YC-14	Aug 77

A test summary precedes each set of figures.

## TEST SUMMARY

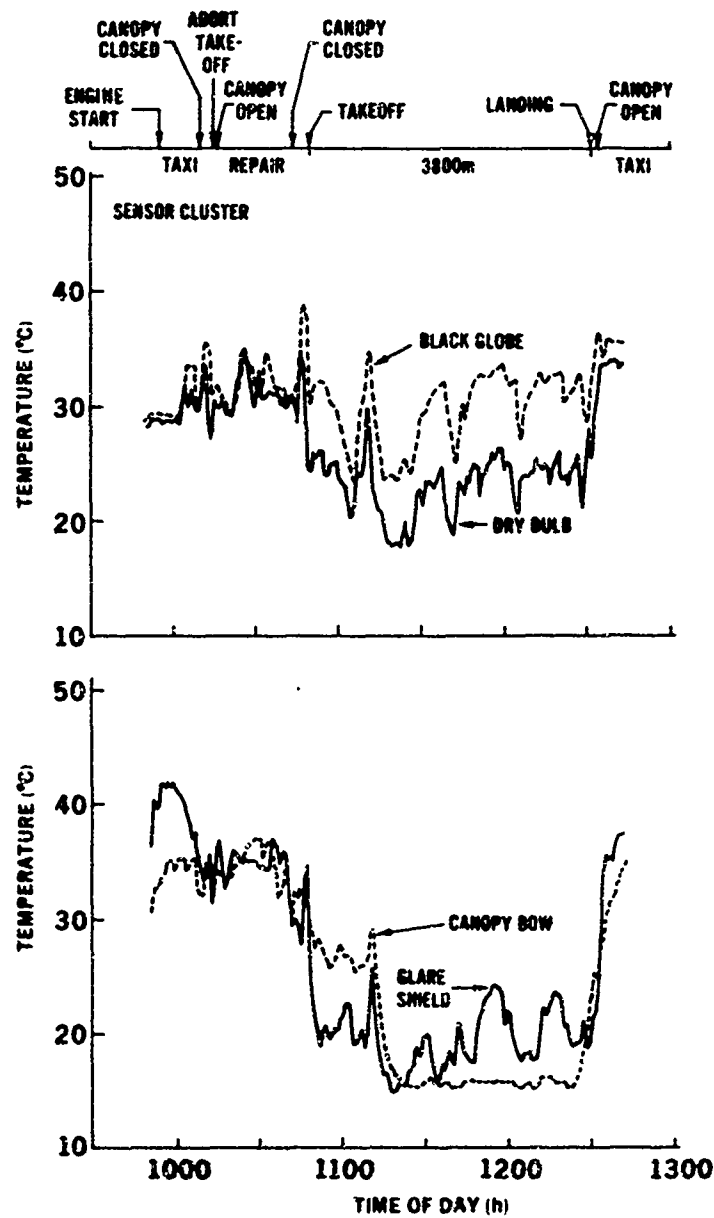
Aircraft: A-7D (#14582)

Dates: 13-15 July 1977

Place: Edwards AFB CA

Sensor Cluster: Located on the right side of the ejection rail, 15 cm above the canopy rail and 30 cm behind the pilot's shoulder.

Additional Sensors: 1. Canopy bow, about 60 cm in front of pilot's forehead.  
2. Inside glare shield, near front instrument panel.  
3. 23 cm from right thigh.  
4. 15 cm from right calf in rudder well.



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUMID [%]	ASS HUMID [mmHg]	PRESSURE [mmHg]	CLOUD COVER	WIND DIR/SPEED
PRETEST:	28.9	-6.1	10	2.91	888.7	CLEAR	240/13
POSTTEST:	32.3	-3.9	9	3.44	888.8	CLEAR	230/15

Figure B-1. A-7D, 13 Jul 77.

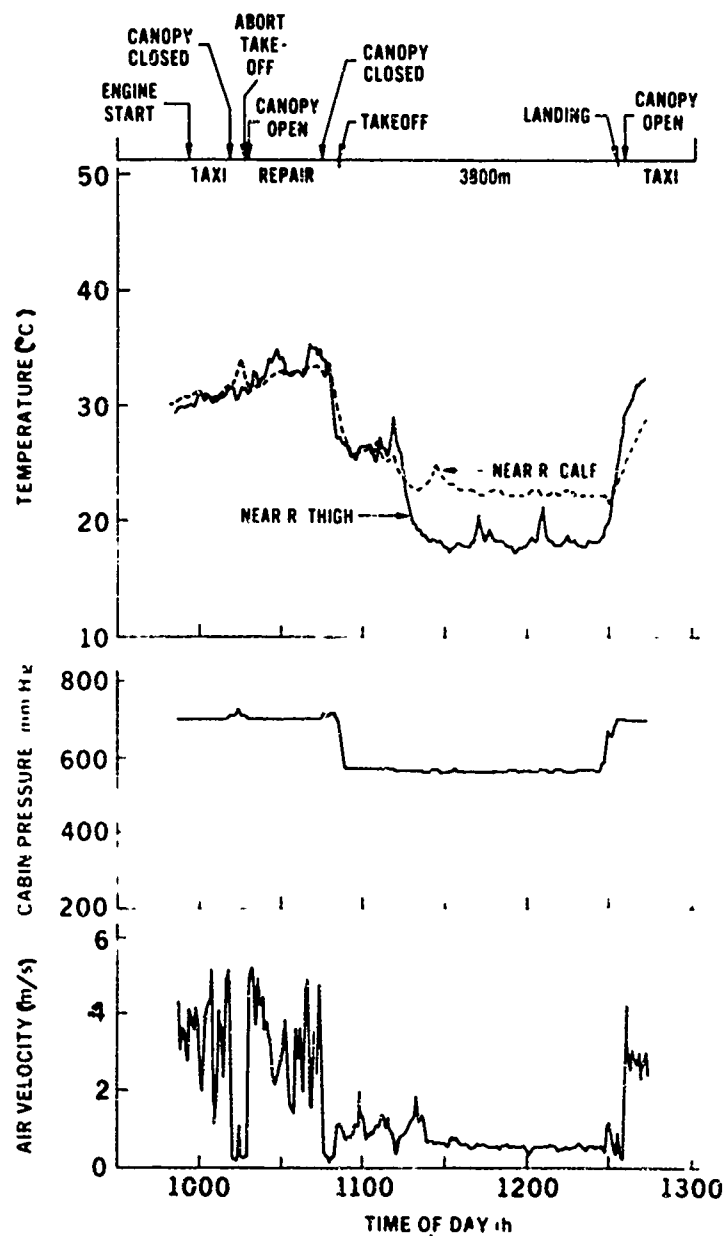
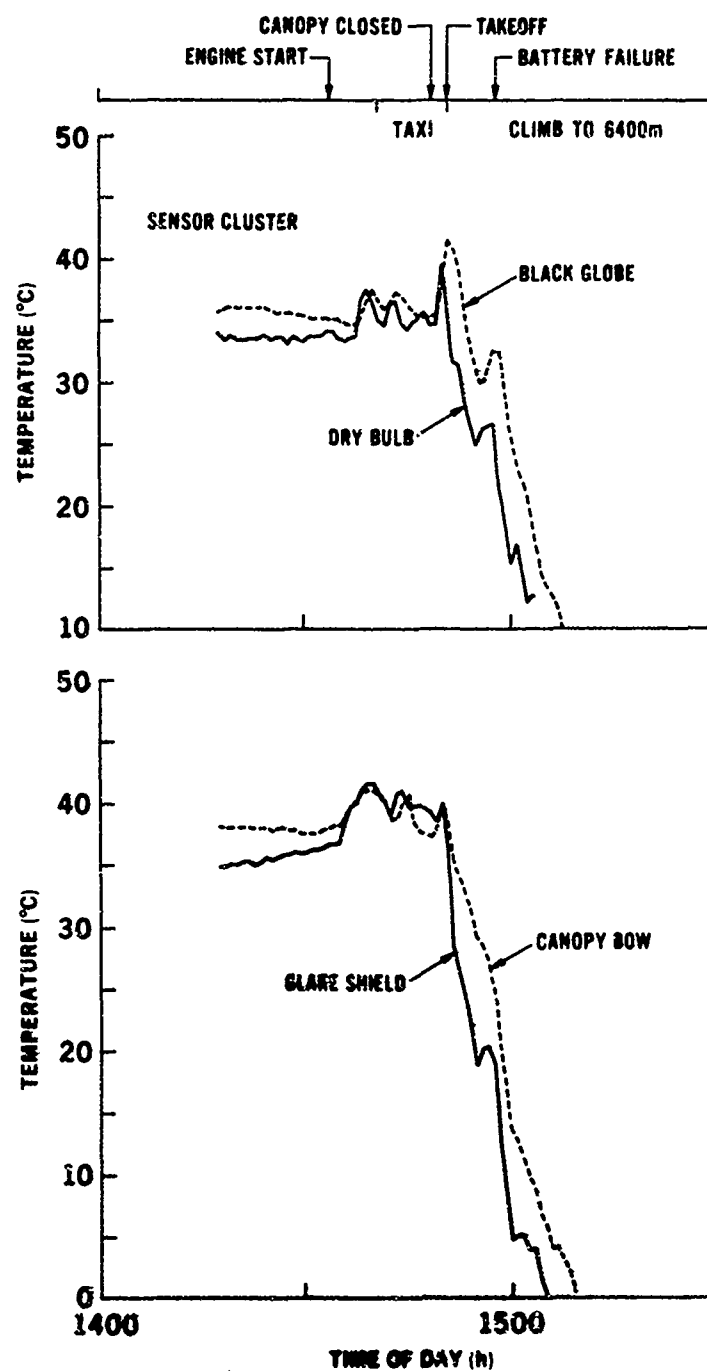


Figure B-1 (continued).



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ASL HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	33.3	-3.8	9	3.44	600.0	CLEAR	230/15
POSTTEST:	—	—	—	—	—	—	—

Figure B-2. A-7D, 13 Jul 77.

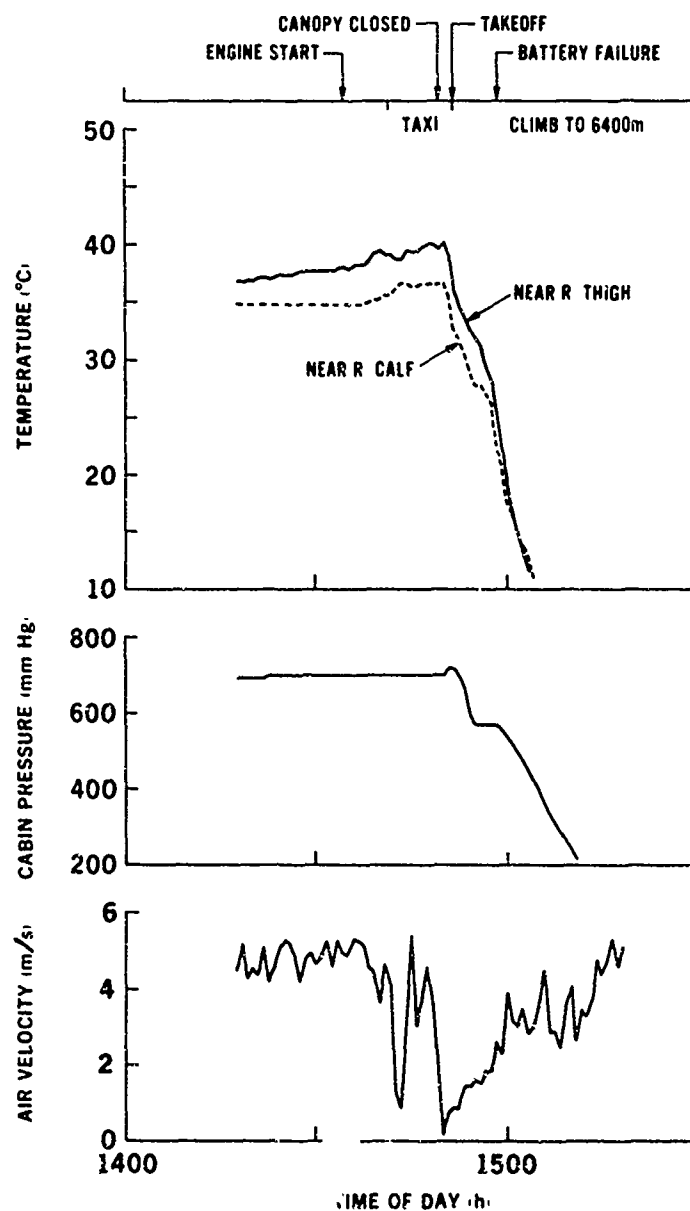
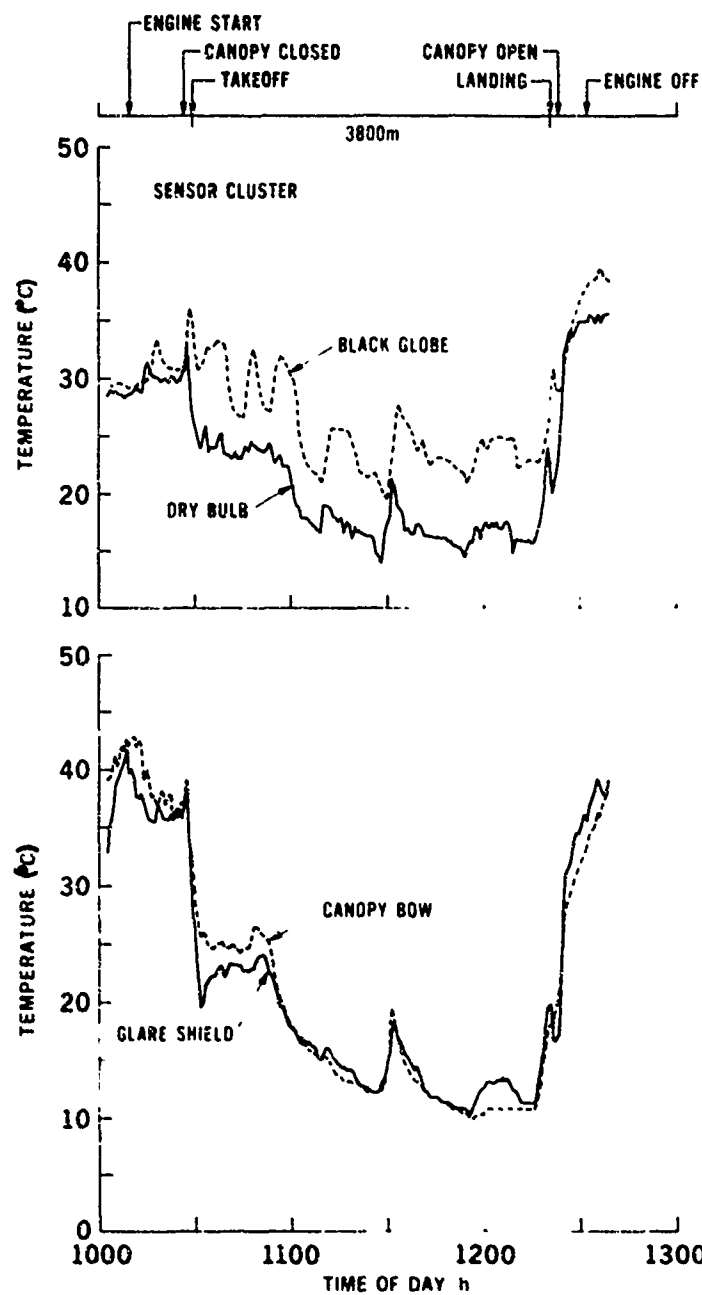


Figure B-2 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST:	28.3	.6	16	4.61	---	CLEAR
POSTTEST:	33.9	-1.1	11	4.23	699.8	CLEAR
						WIND DIR, SPEED 199/4 0/1

Figure B-3. A-7D, 14 Jul 77.

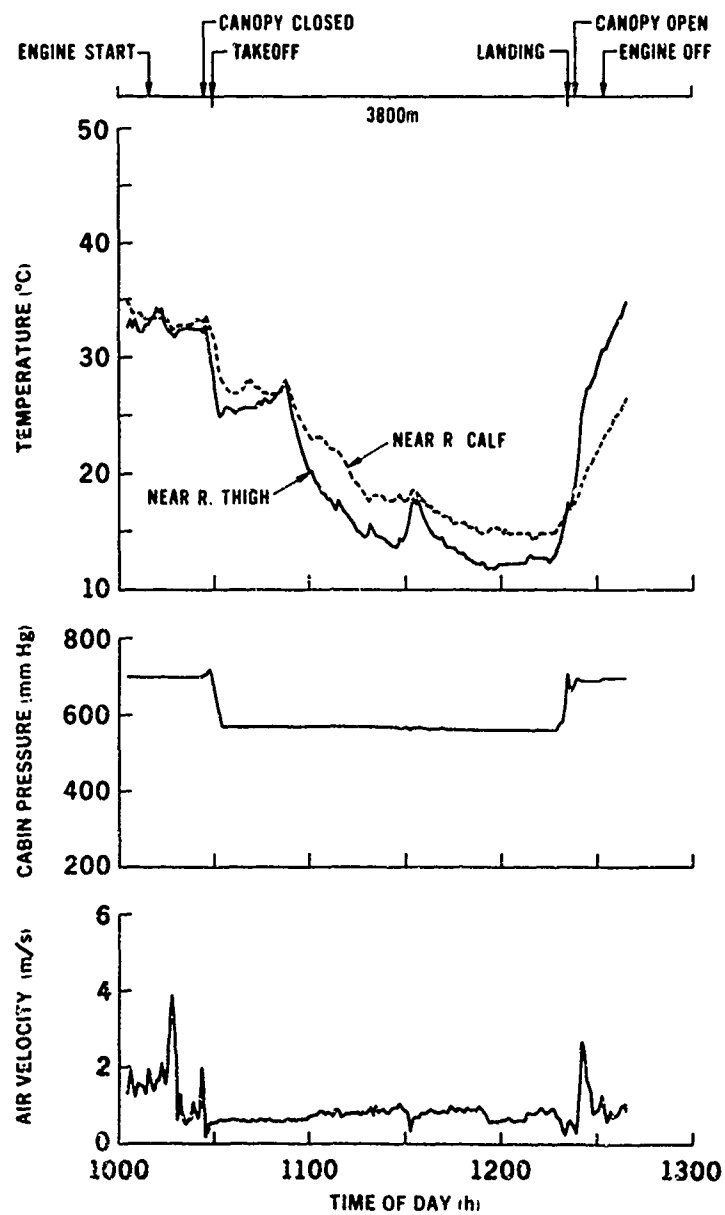
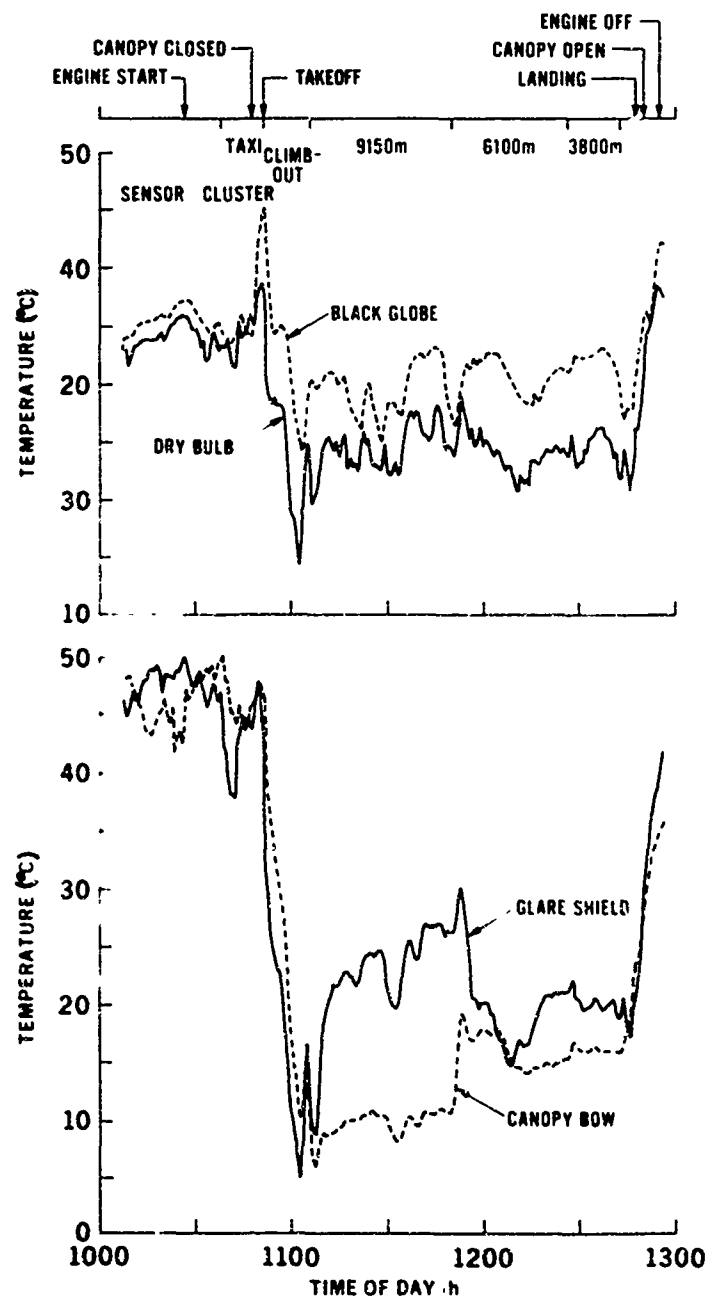


Figure B-3 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST	20.3	0.0	16	4.58	700.3	0
POSTTEST	33.3	1.7	13	5.18	700.5	1900 m, SCAT CALM 3850 m, BRK

Figure B-4. A-7D, 15 Jul 77.

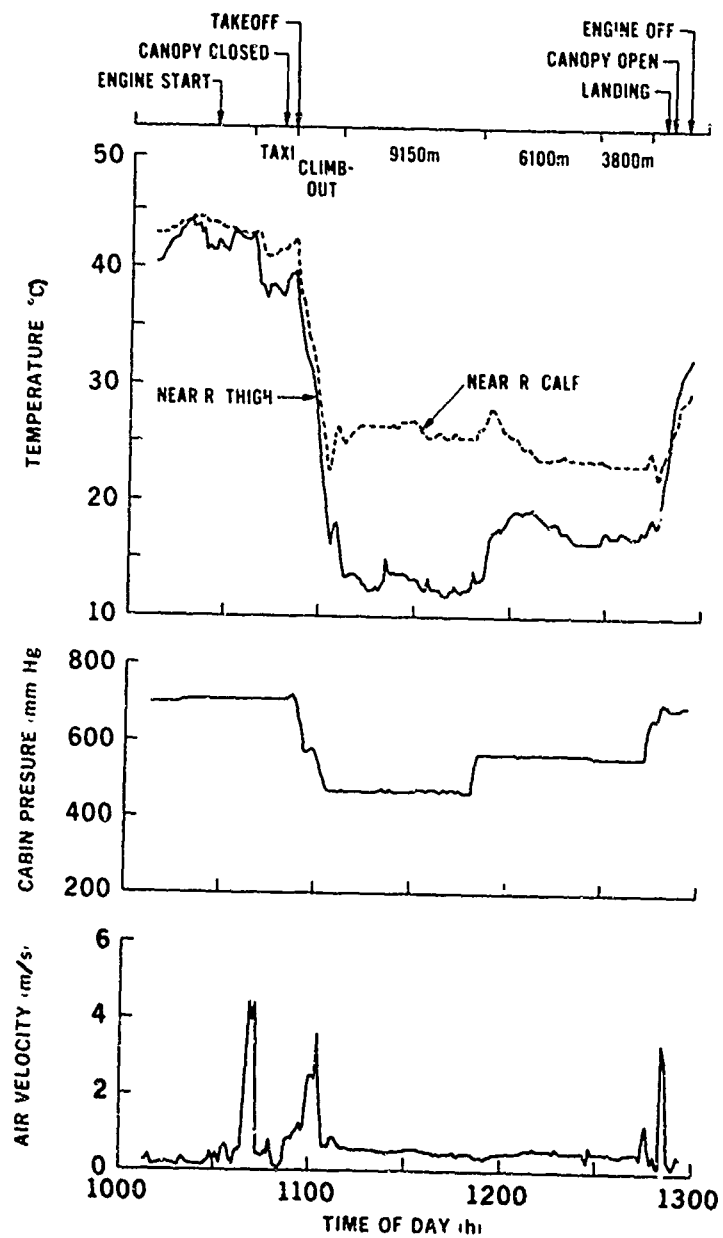


Figure B-4 (continued).

## TEST SUMMARY

Aircraft: A-10 (#669)

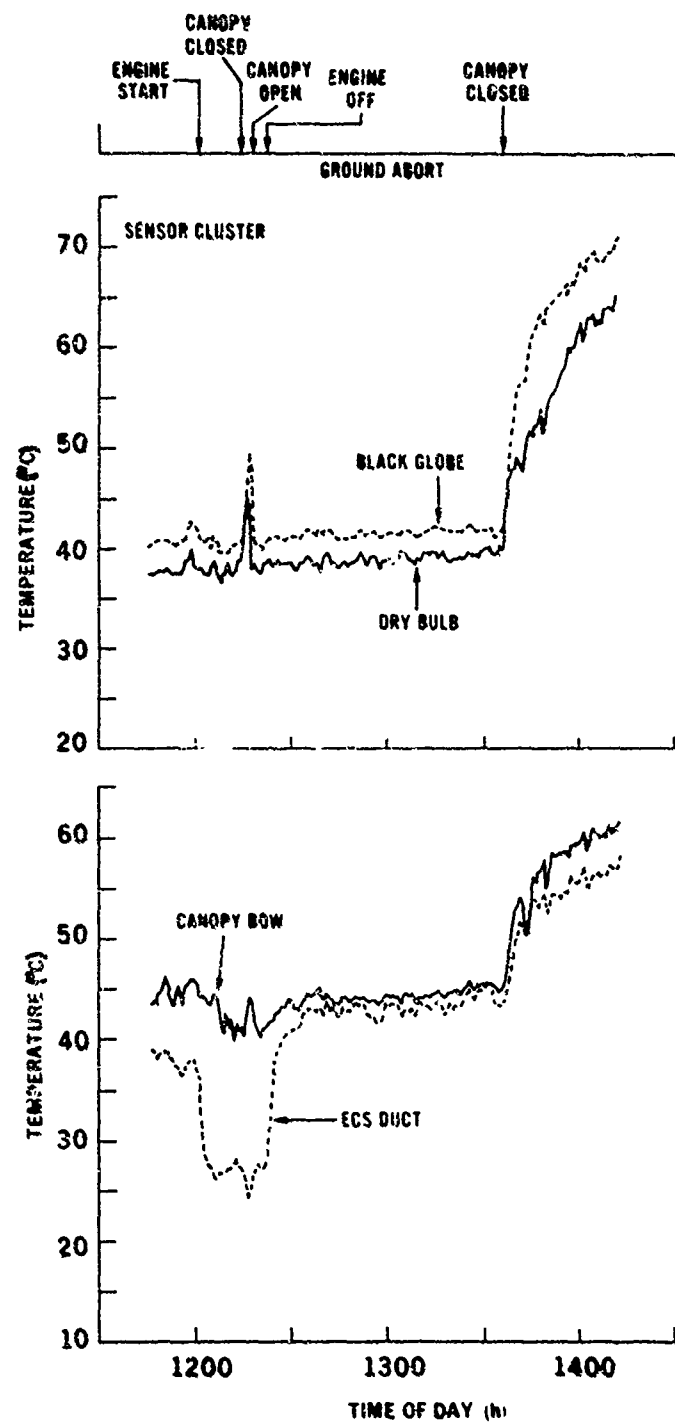
Dates: 5-11 August 1977

Place: Edwards AFB CA

Sensor Cluster: Located on the canopy swing arm behind the pilot's head,  
30 cm above the rear deck and 30 cm behind the seat.

Additional Sensors: 1. Canopy bow, about 60 cm in front of pilot's forehead.  
2. Under glare shield, near climb indicator.  
3. Right rudder well, near knee.  
4. Right ECS inlet duct.

PRECEDING PAGE BLANK-NOT FILMED



AIRFIELD CLIMATIC CONDITIONS						
DRY BULB	DEW POINT	REL HUM	ABS HUM	PRESSURE	CLOUD COVER	WIND DIR/SPEED
(°C)	(°C)	(%)	(mmHg)	(mmHg)		
PRETEST: --	--	--	--	--	--	--
POSTTEST: --	--	--	--	--	--	--

Figure B-5. A-10, 5 Aug 77.

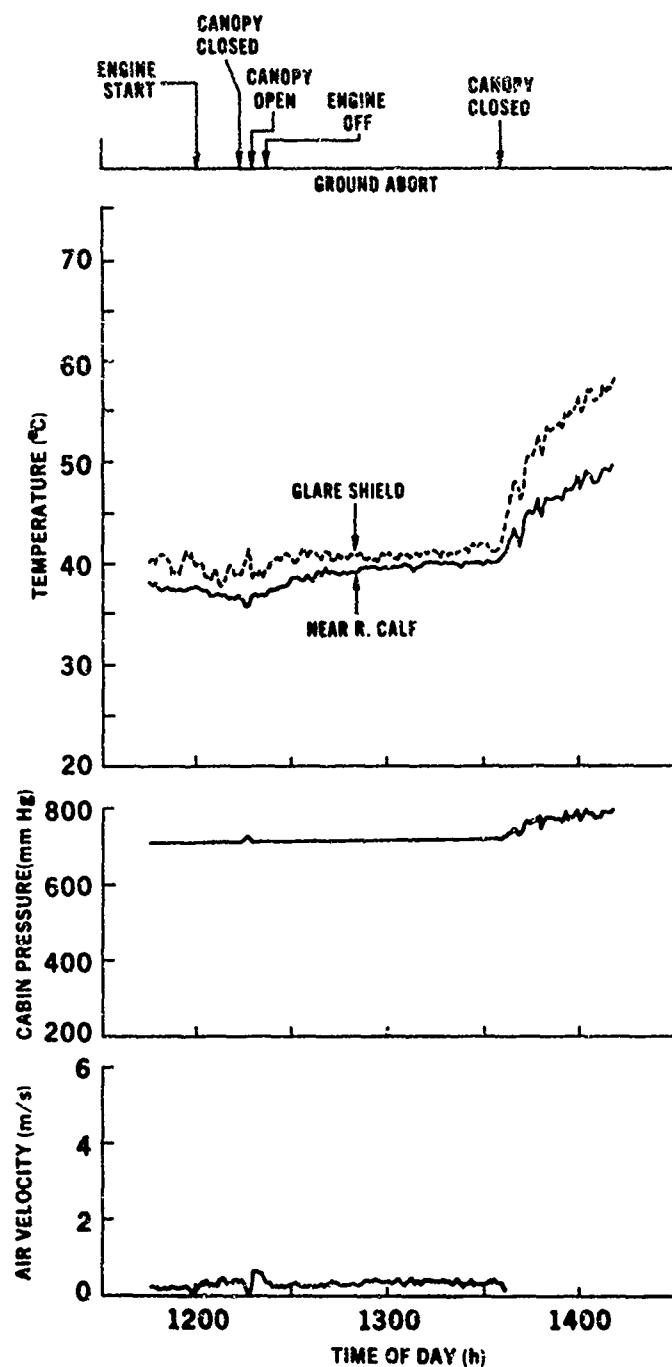
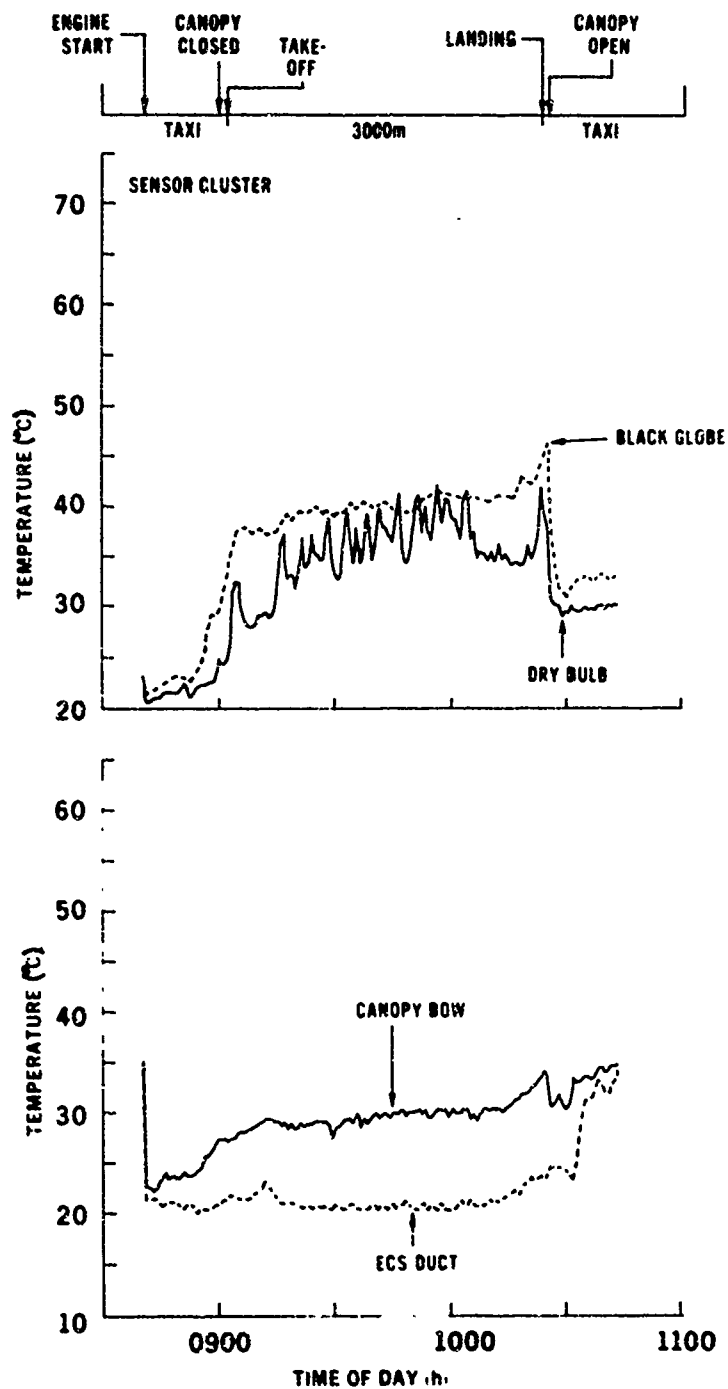


Figure B-5 (continued).



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	22.2	5.0	32	6.5	999.0	CLEAR	CALM
POSTTEST:	30.0	6.1	22	7.1	999.5	CLEAR	CALM

Figure B-6. A-10, 8 Aug 77.

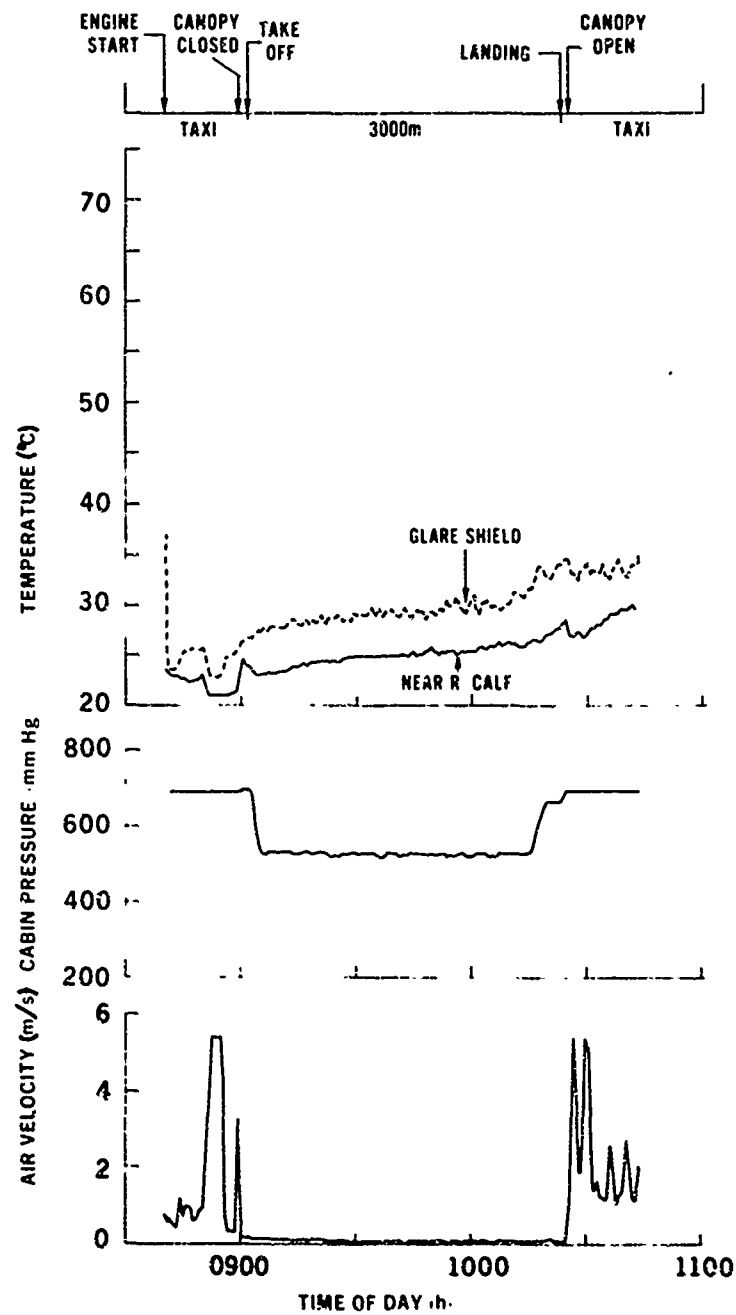
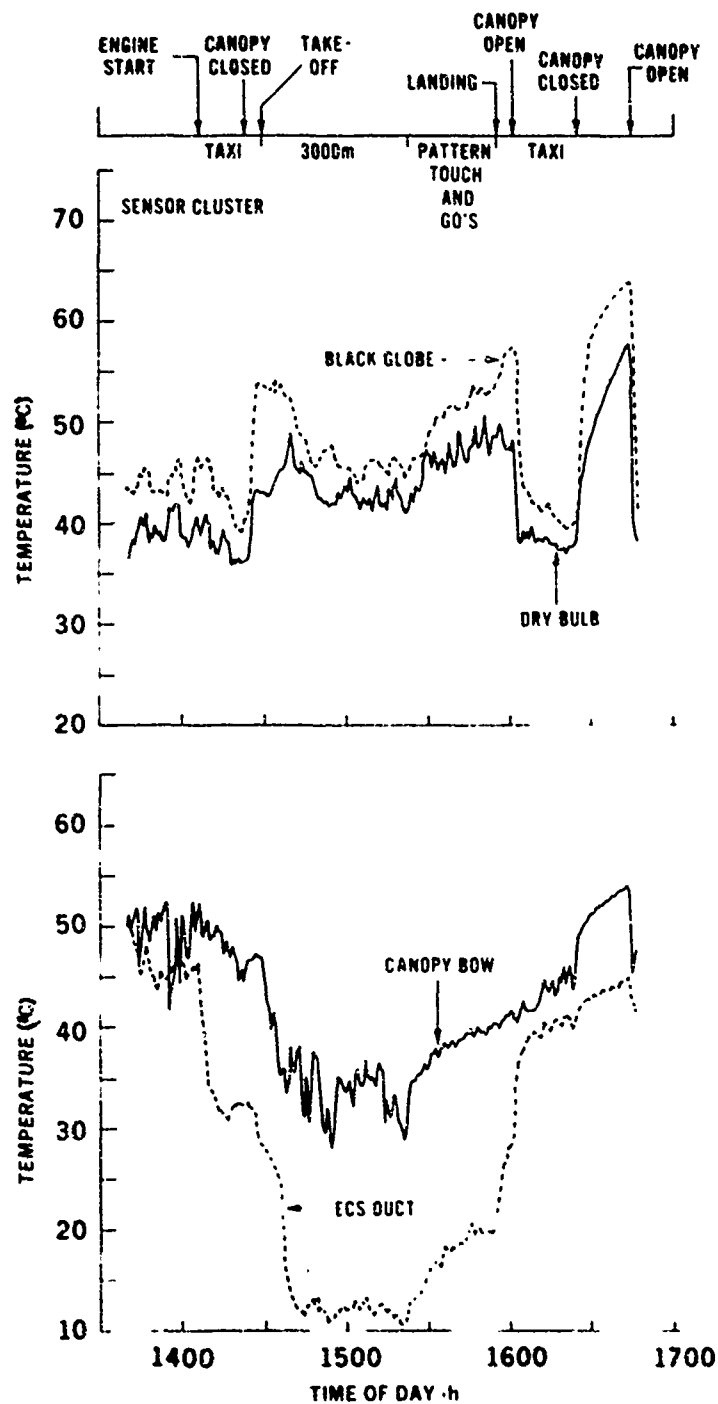


Figure B-6 (continued).



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL. HUM. [%]	ABS HUM. [mmHg]	PRESSURE [mmHg]	CLOUD COVER	WIND DIR./SPEED
PRETEST:	35.6	1.1	11	5.8	999.2	CLEAR	190/4
POSTTEST:	36.7	1.1	11	5.9	997.7	CLEAR	210/3

Figure B-7. A-10, 9 Aug 77.

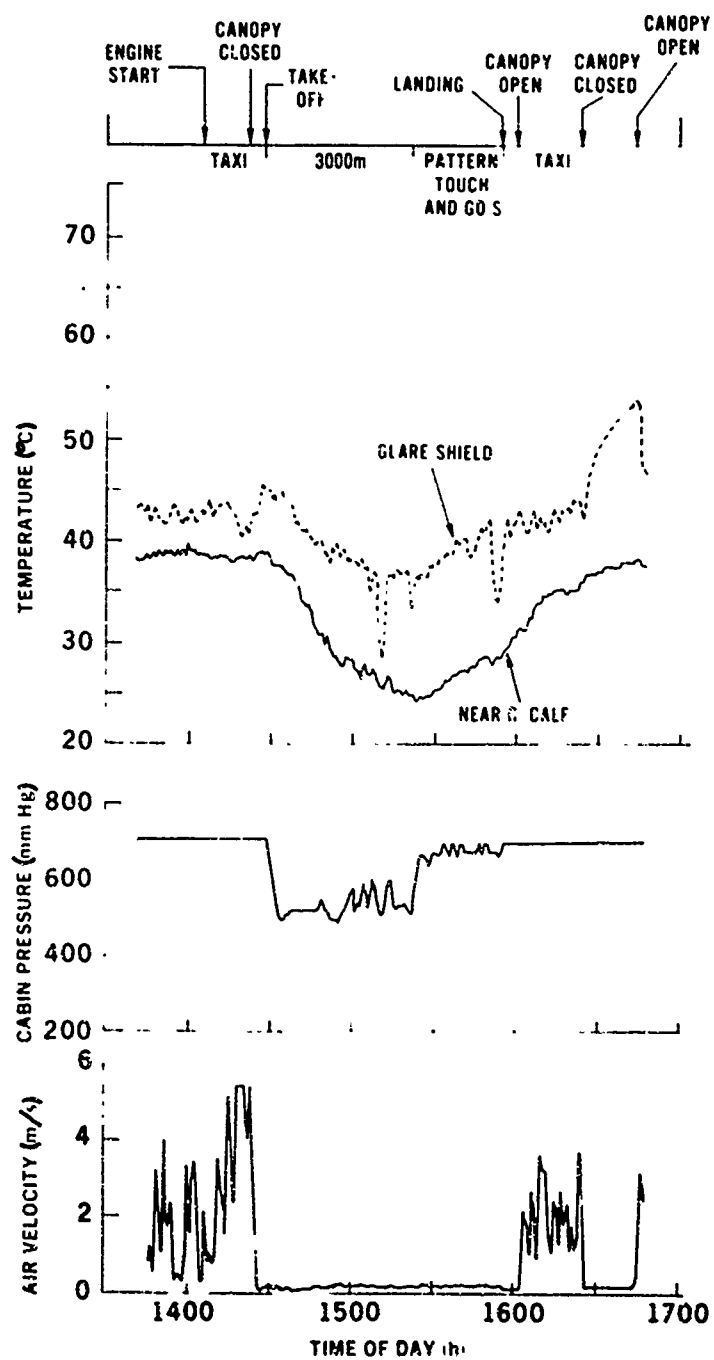


Figure B-7 (continued).

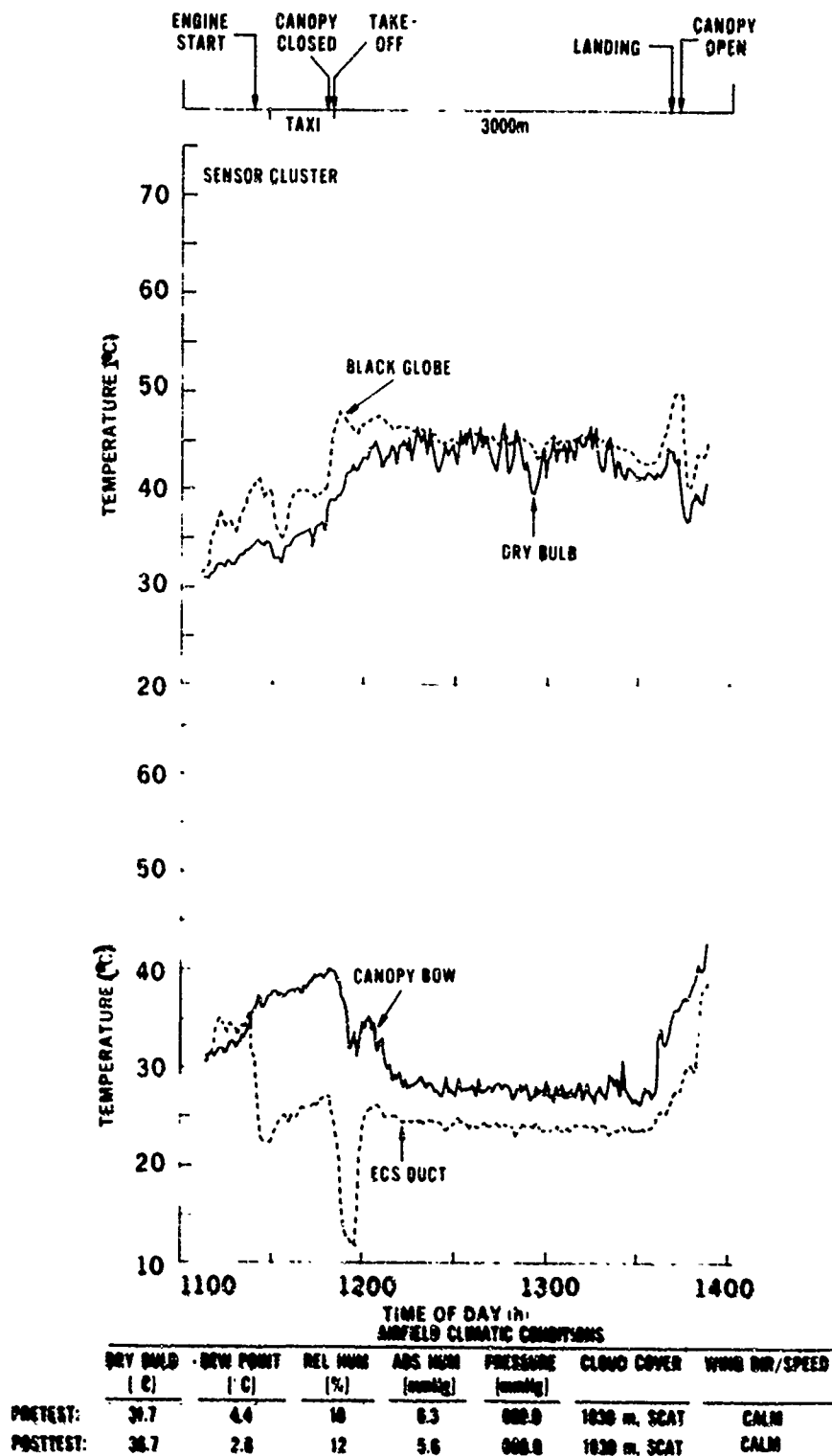


Figure B-8. A-10, 11 Aug 77.

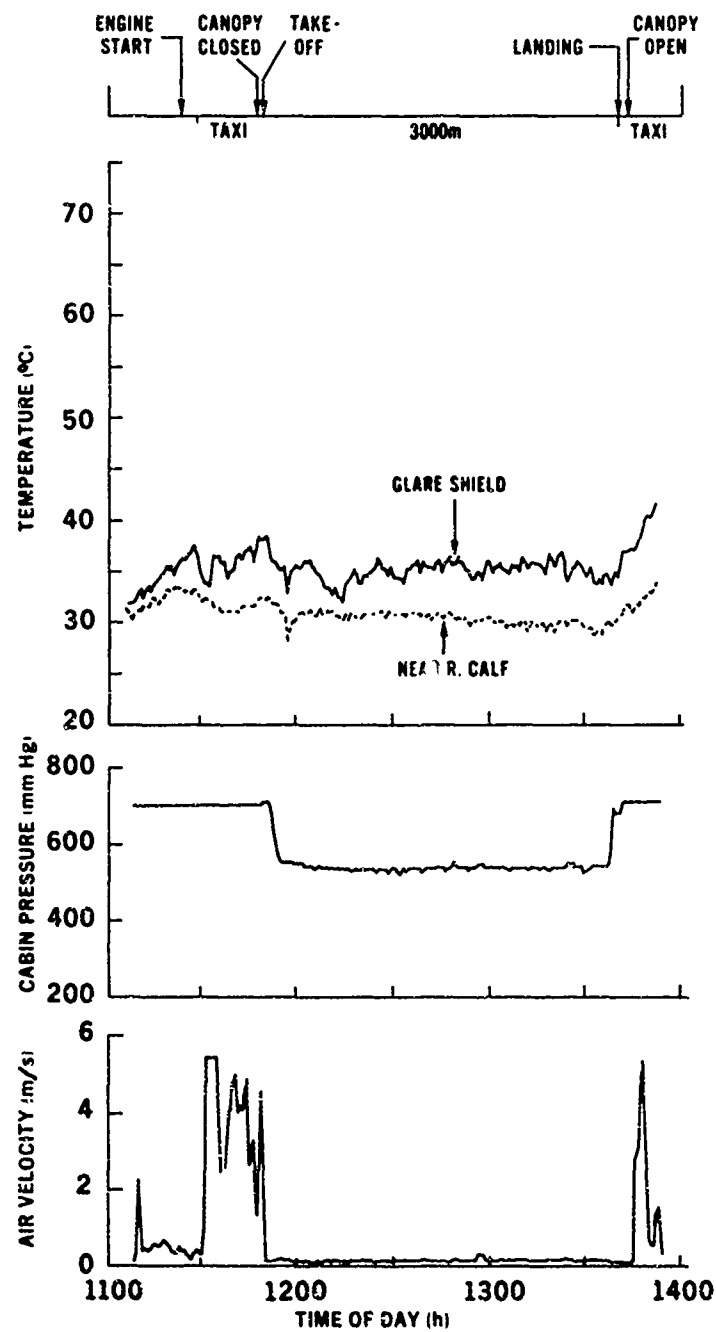


Figure B-8 (continued).

TEST SUMMARY

Aircraft: F-15 (AECS) (#282) and F-15 (#288)

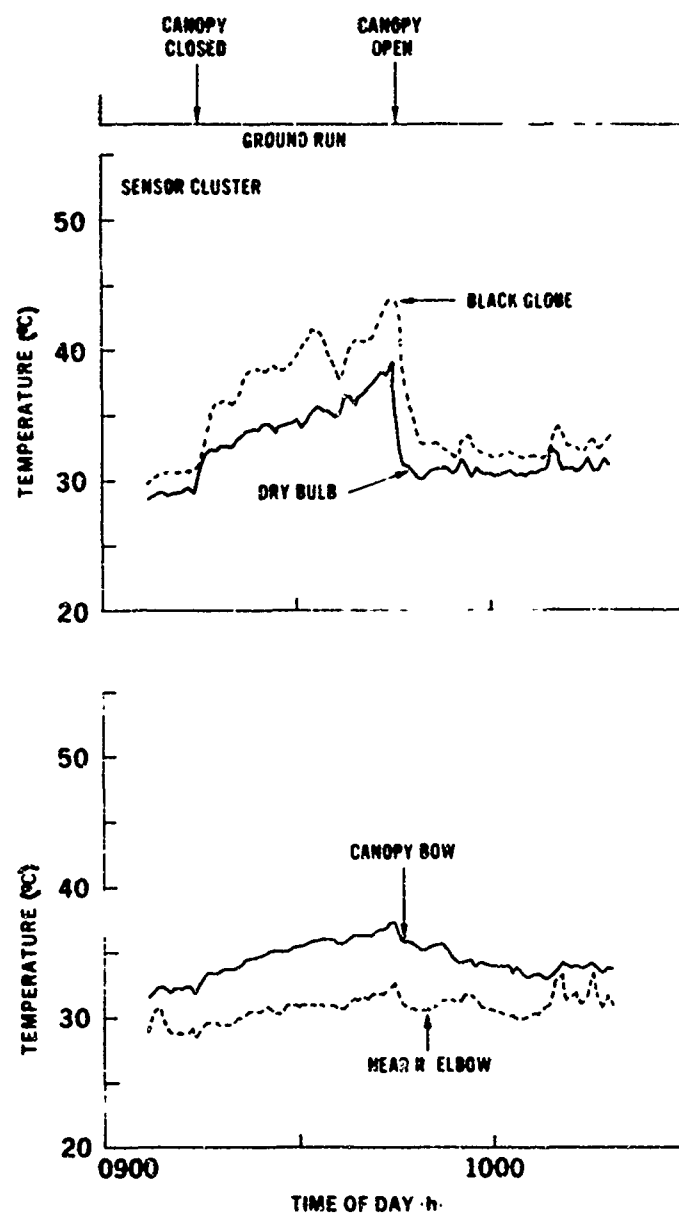
Dates: 25 Aug - 21 Sep 77

Places: Beeville NAS TX and Edwards AFB CA

Sensor Cluster: Located on right side on test camera mount, about shoulder height and 15 cm aft of seat.

Additional Sensors: 1. Canopy bow, on ECS inlet duct.  
2. Glare shield, 60 cm in front of pilot.  
3. 23 cm from right elbow.  
4. 15 cm from right calf, in rudder well.

PRECEDING PAGE BLANK-NOT FILMED



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (g/m <sup>3</sup> )	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	28.7	23.9	75	22.2	755.4	SCAT	170/9
POSTTEST:	28.3	22.8	72	20.8	755.7	SCAT	180/10

Figure B-9. F-15 (AECS), 25 Aug 77.

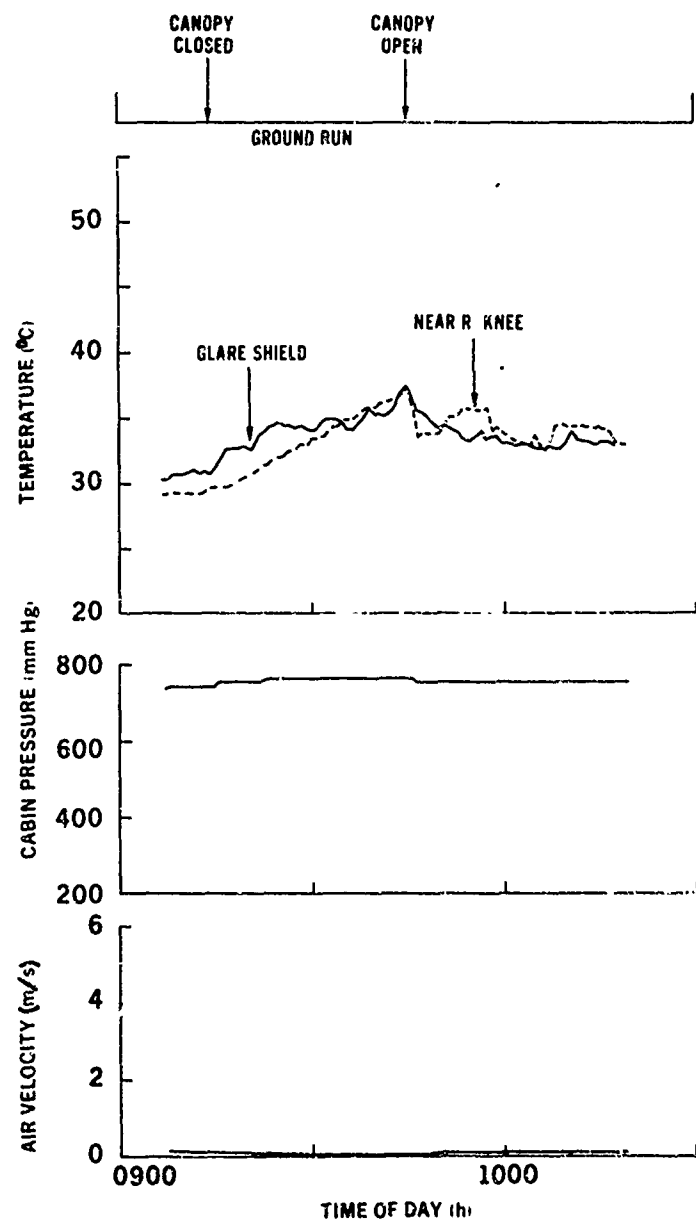
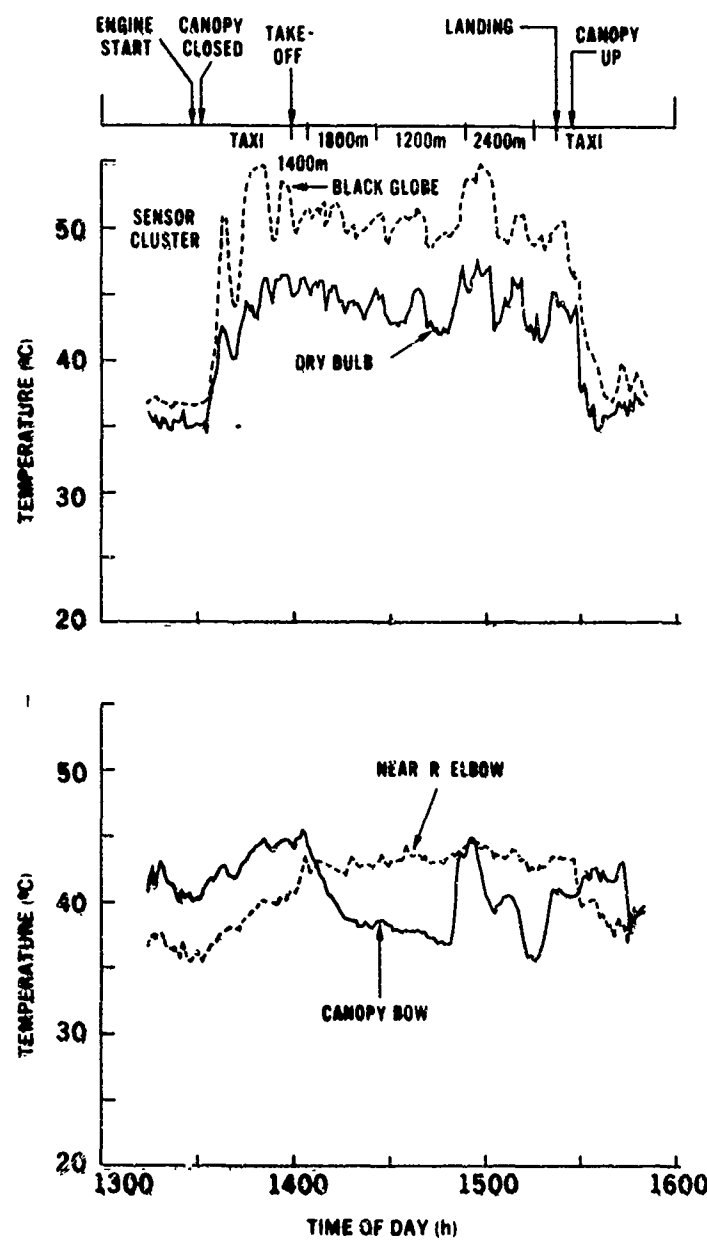


Figure B-9 (continued).



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	33.9	21.1	47	18.8	754.6	1050 m, SCAT	150/10
POSTTEST:	34.4	21.1	40	18.8	753.9	---	100/13

Figure B-10. F-15 (AECS), 25 Aug 77.

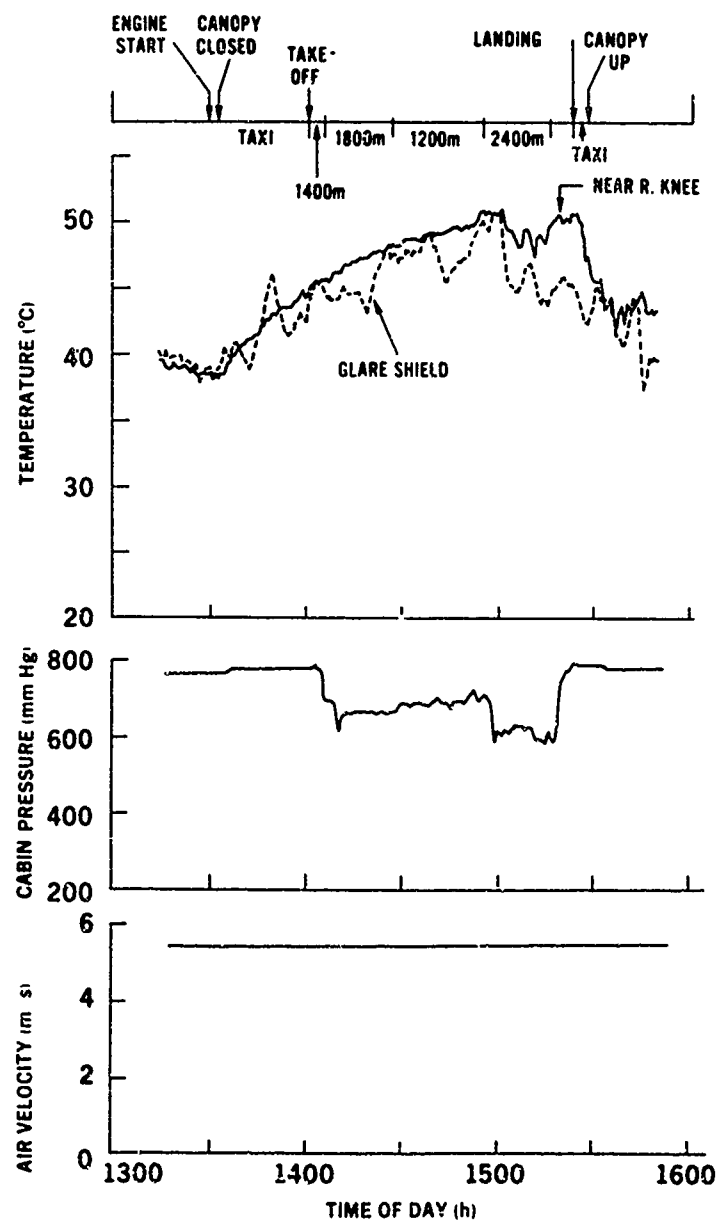
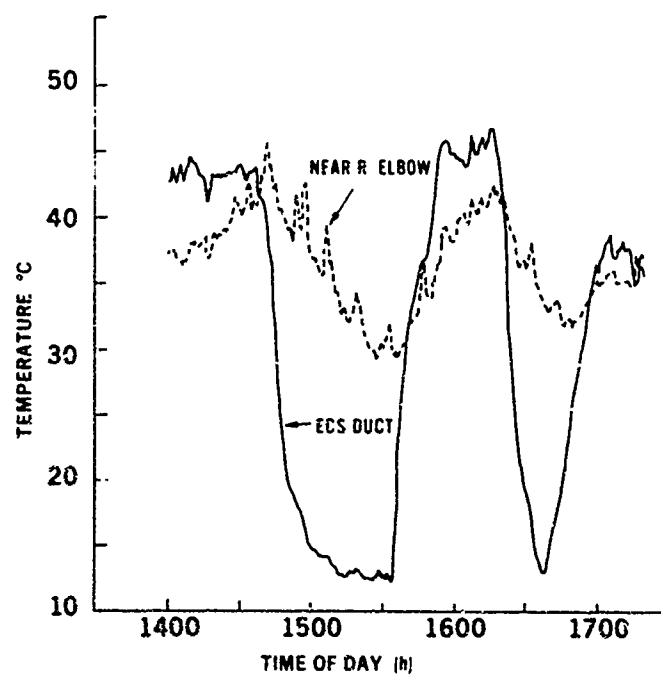
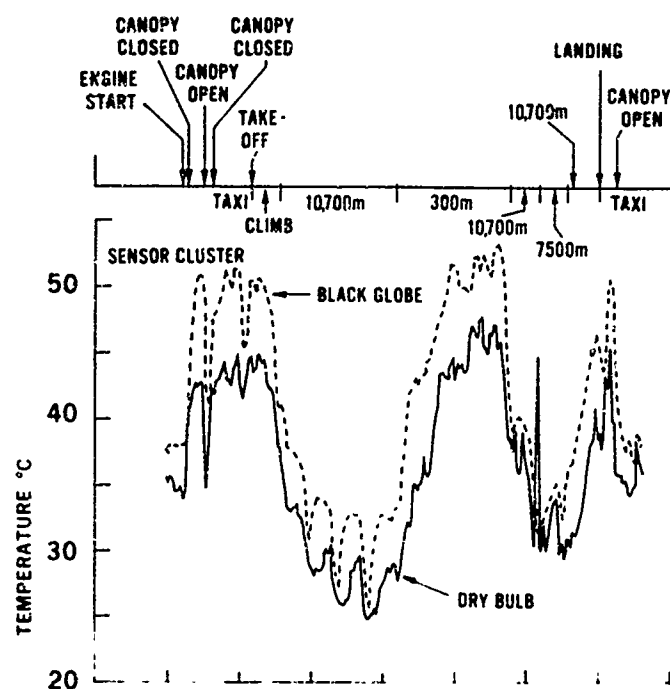


Figure 10 (continued).



	AIRFIELD CLIMATIC CONDITIONS					
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST:	35.0	20.0	41	17.5	754.9	1050 m, BRK
POSTTEST:	34.4	20.9	43	17.5	753.9	1050 m, BRK
						WIND DIR, SPEED
						150, 11
						140, 10

Figure B-11. F-15 (AECS), 26 Aug 77.

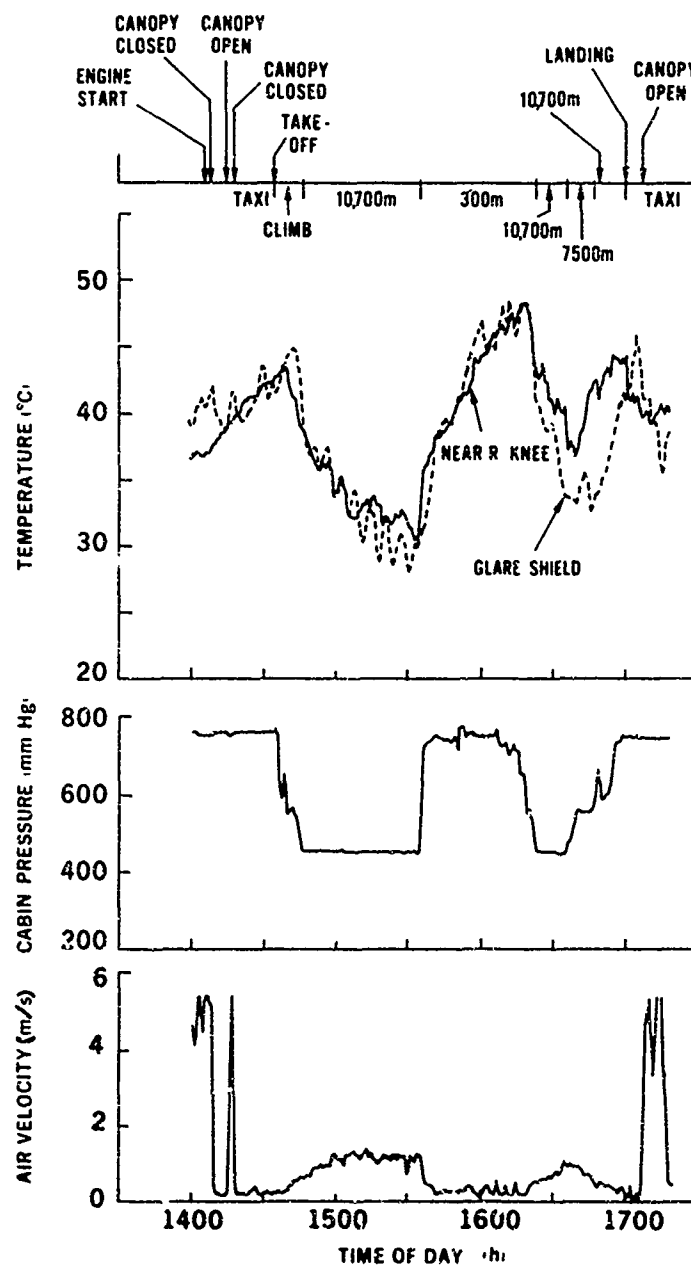
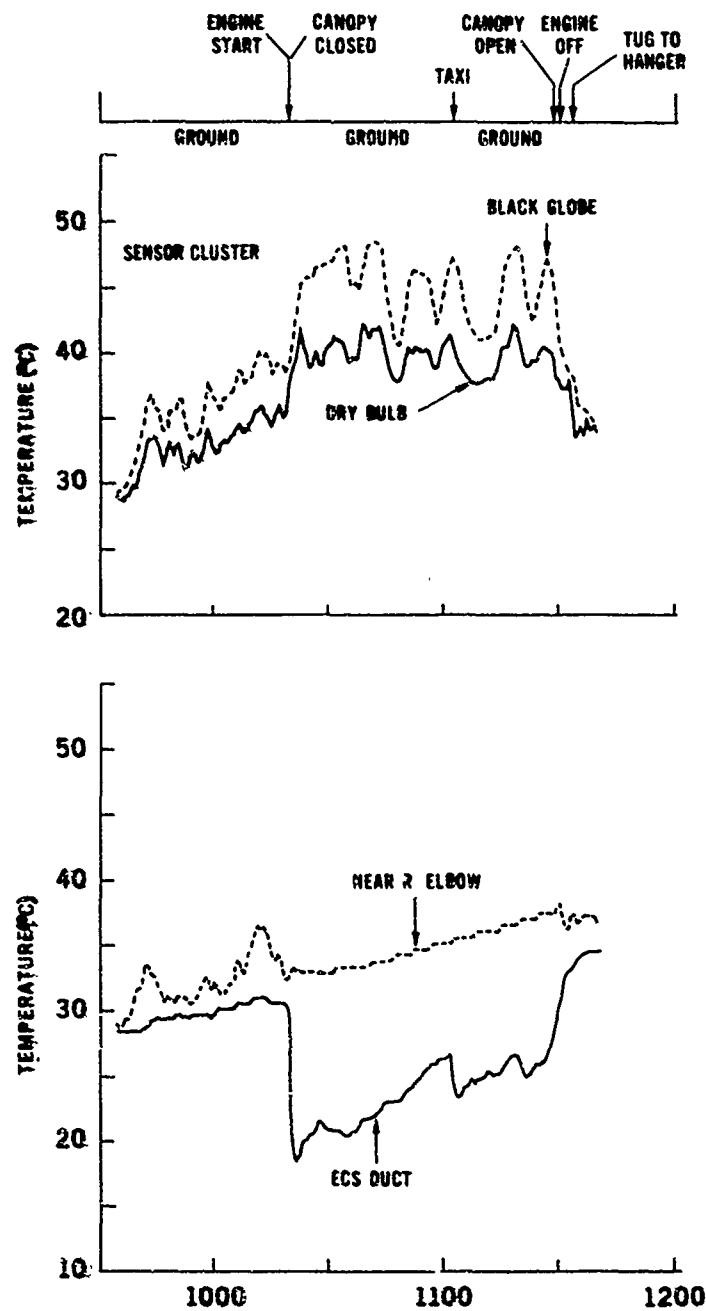


Figure B-11 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ABS HUM [mmHg]	PRESSURE [mmHg]	CLOUD COVER
PRETEST:	28.1	25.8	94	23.8	751.2	175 m, BKN
POSTTEST:	30.8	22.8	84	20.9	758.9	100 m, BKN
						WIND DIR/SPEED
						084/05
						089/02

Figure B-12. F-15 (AECS), 29 Aug 77.

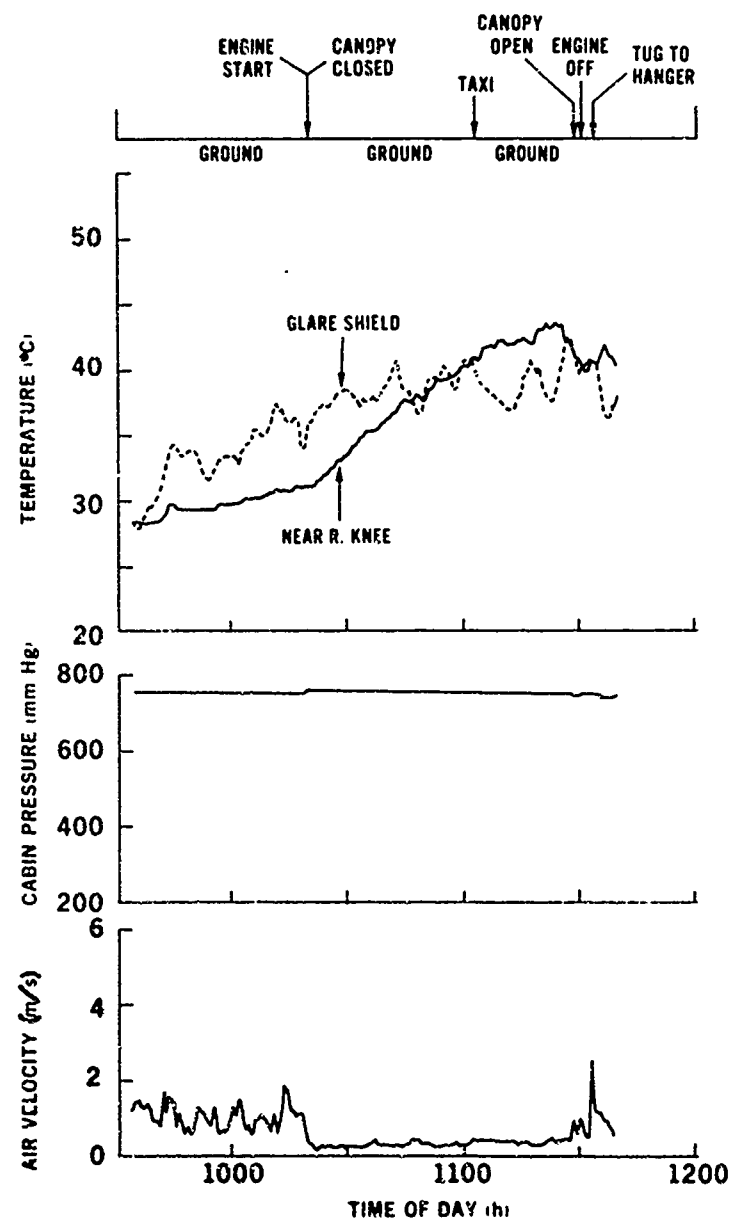
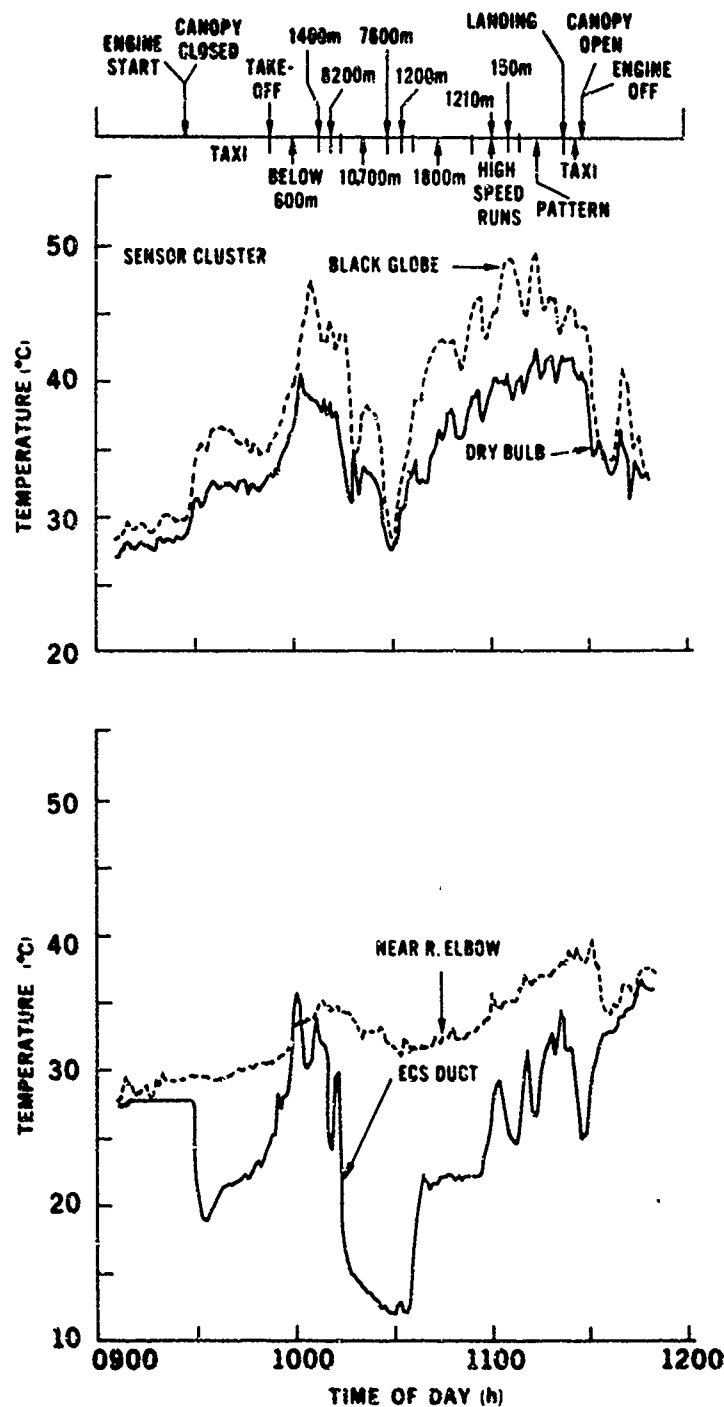


Figure B-12 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST:	25.6	22.3	88	21.5	755.7	220 m, 30%
POSTTEST:	30.6	22.2	63	26.1	756.7	700 m, 80%
						WIND DIR/SPEED
						620/6
						800/6

Figure B-13. F-15 (AECS), 30 Aug 77.

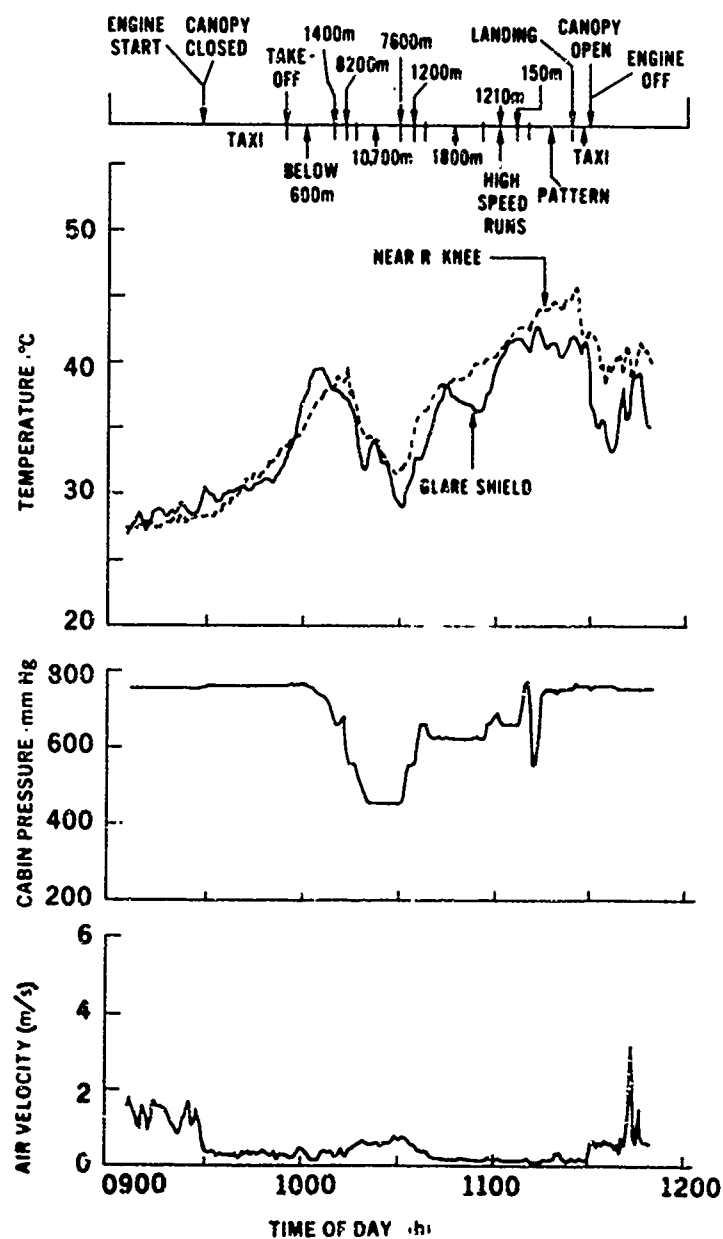
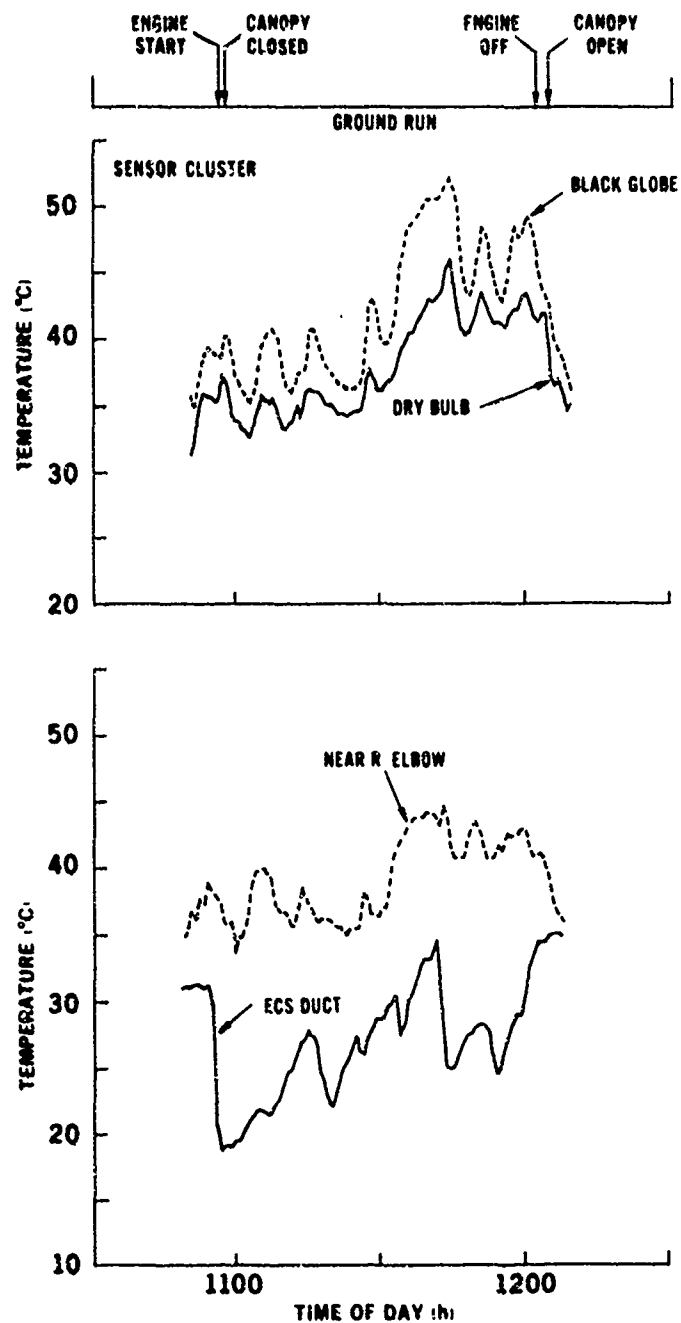


Figure B-13 (continued).



	AIRFIELD CLIMATE CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (g/m <sup>3</sup> )	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	30.3	22.8	72	25.8	754.4	700 m, BRK	020/6
POSTTEST:	28.4	23.3	68	21.5	735.7	790 m, BRK	020/6

Figure B-14. F-15 (AECS), 31 Aug 77.

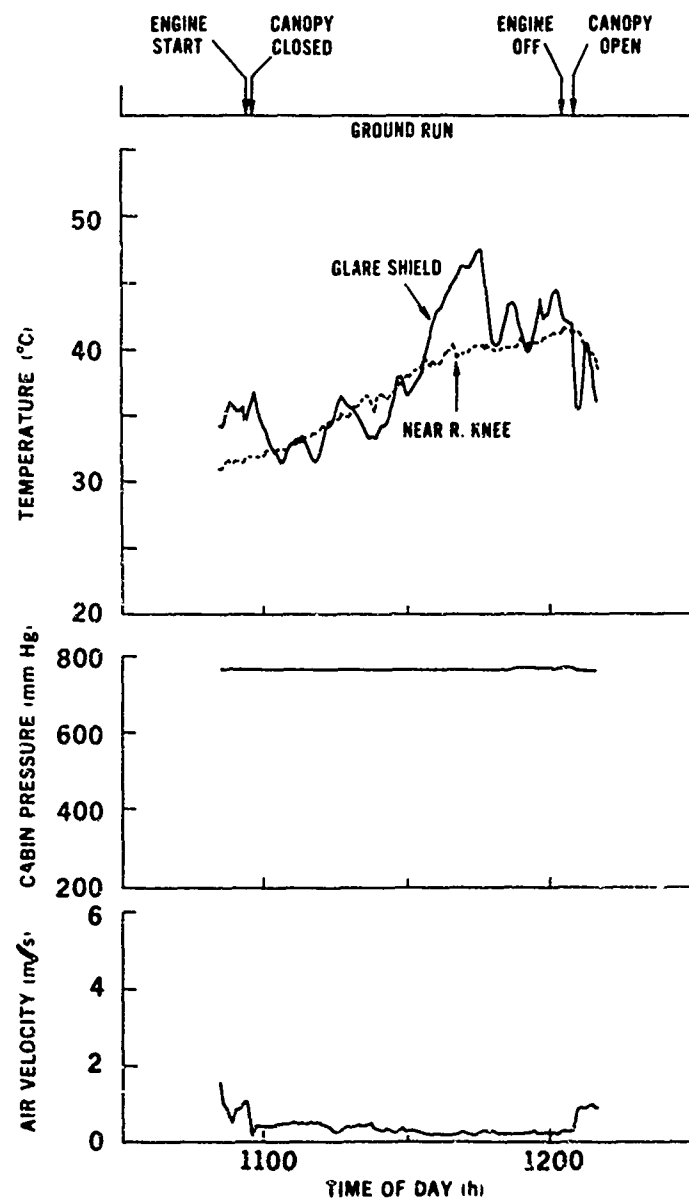
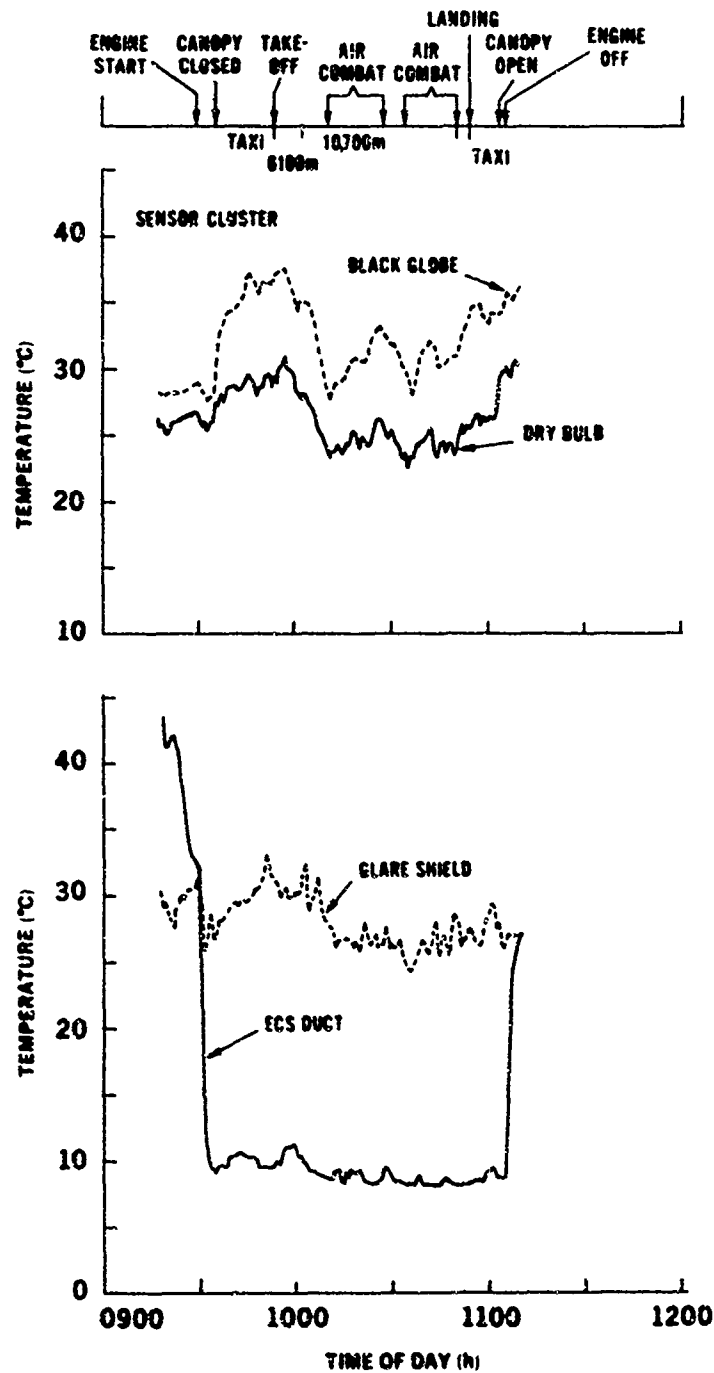


Figure B-14 (continued).



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUMID [%]	AIR PRESS [mmHg]	PRESSURE [mmHg]	CLOUD COVER	WIND/DIR/SPEED
PRETEST:	--	--	--	--	--	--	--
POSTTEST:	--	--	--	--	--	--	--

Figure B-15. F-15, 13 Sep 77.

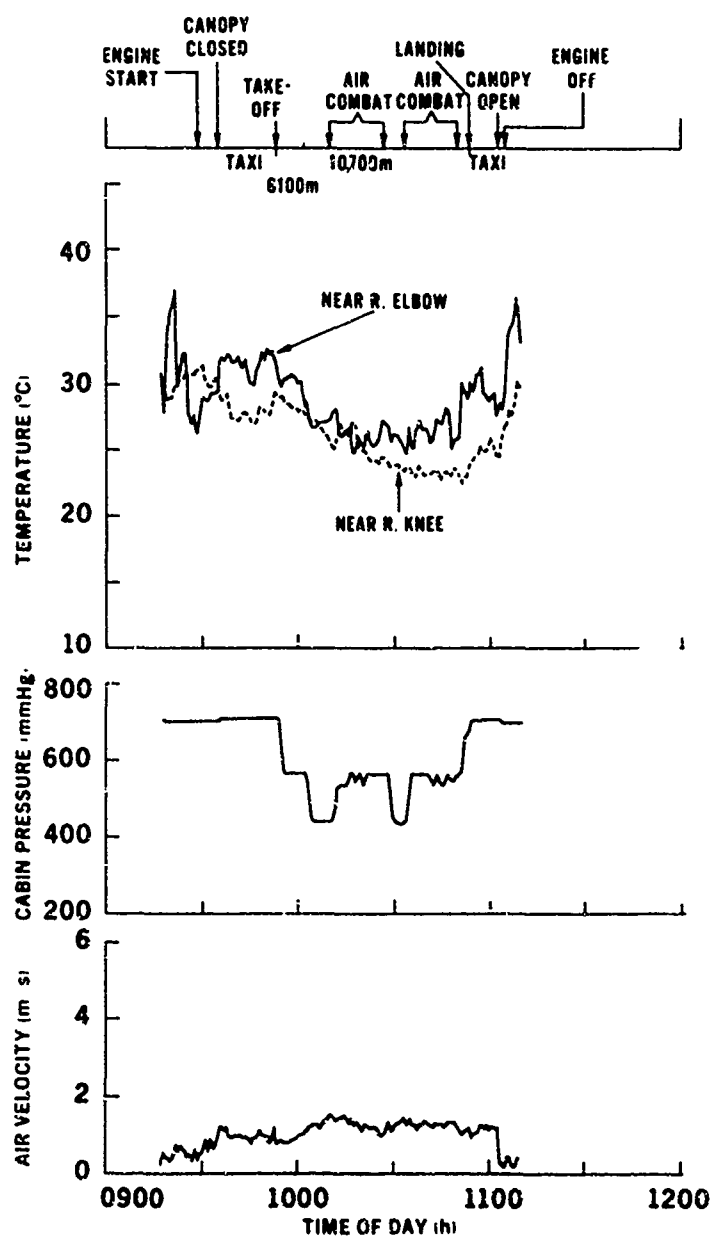
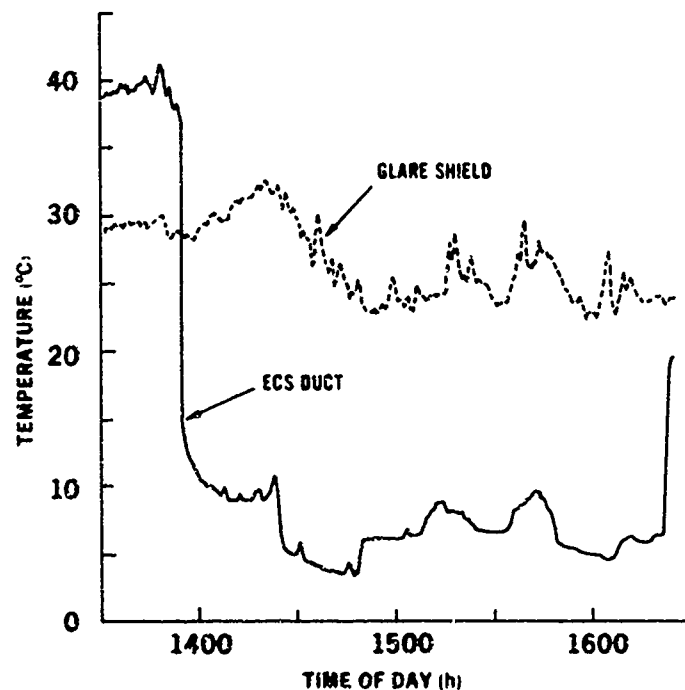
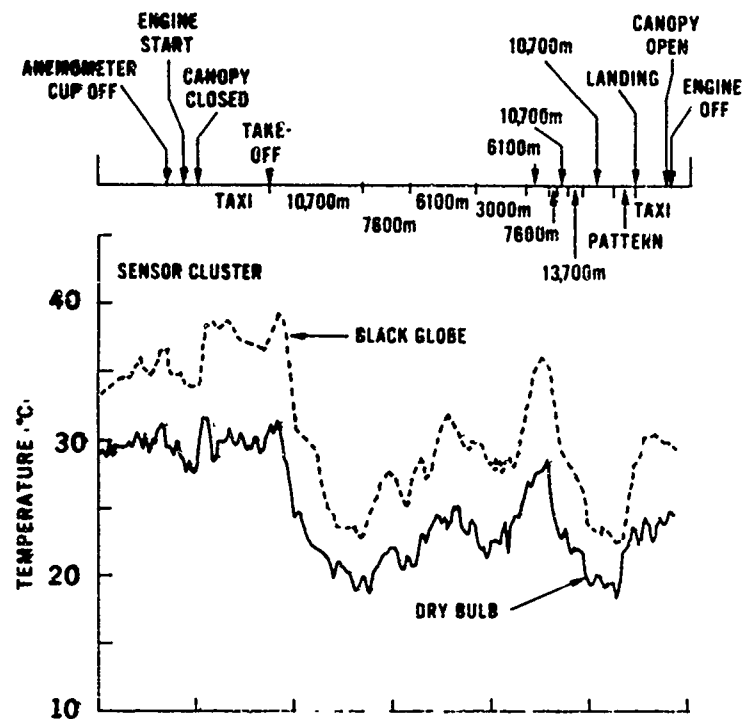


Figure B-15 (continued).



AIRFIELD CLAMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ABS HUM [mmHg]	PRESSURE [mmHg]	CLOUD COVER
PRETEST:	27.2	4.4	20	8.3	886.2	CLEAR
POSTTEST:	25.8	8.9	35	8.5	886.0	CLEAR
						WIND DIR/SPEED
						220/18
						220/20

Figure B-16. F-15, 15 Sep 77.

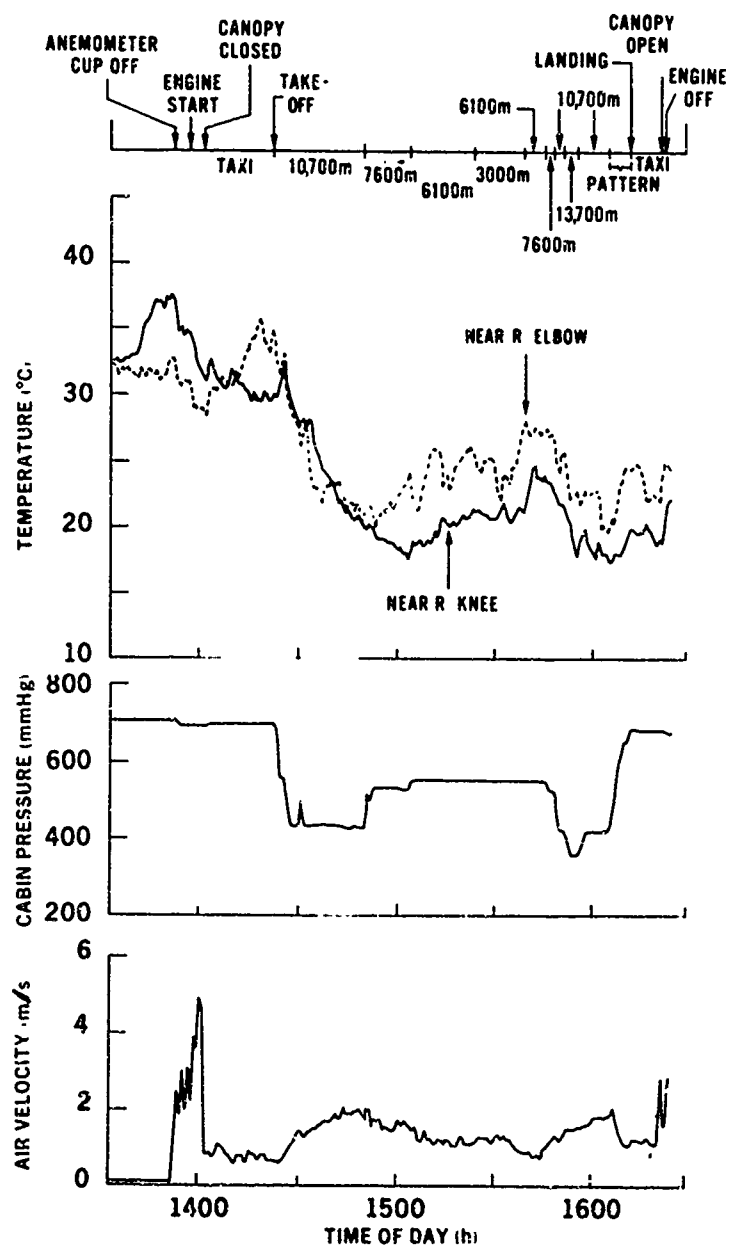
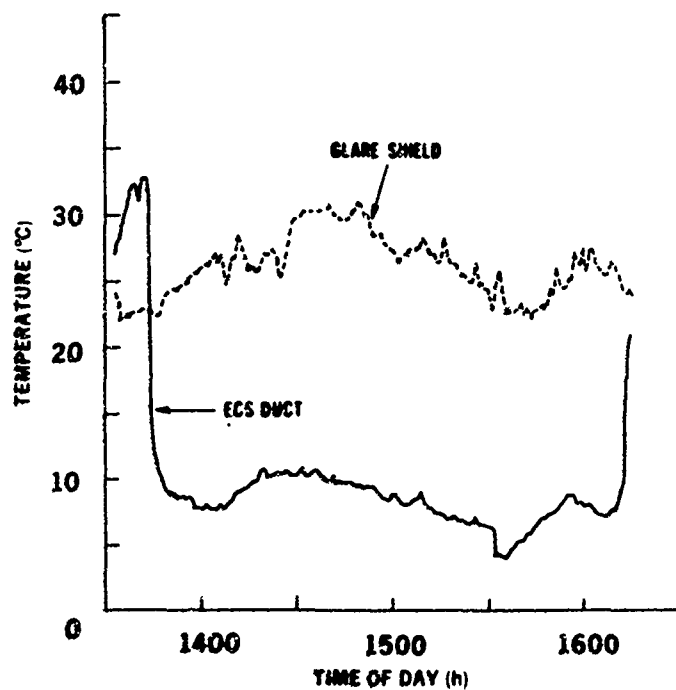
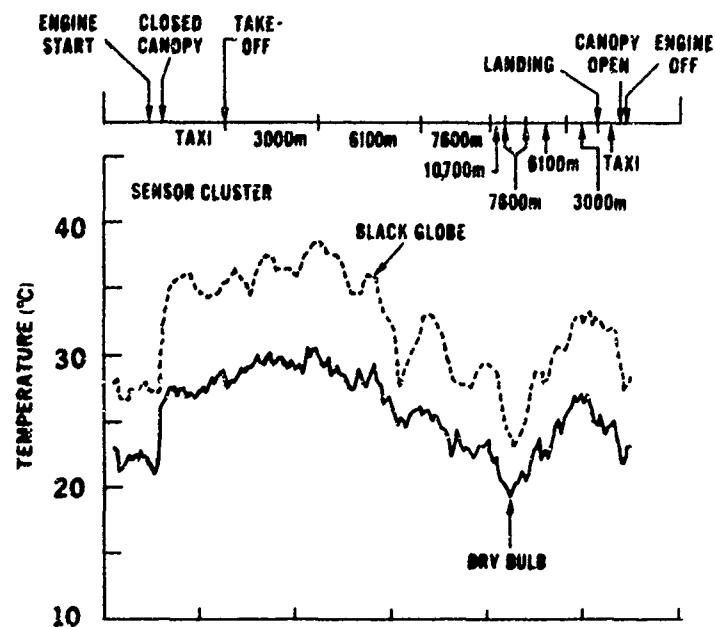


Figure B-16 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST:	21.8	8.7	37	7.4	898.9	CLEAR
POSTTEST:	21.3	8.7	38	7.4	897.7	CLEAR
						WIND DIR/SPEED
						240/16
						230/10

Figure B-17. F-15, 16 Sep 77.

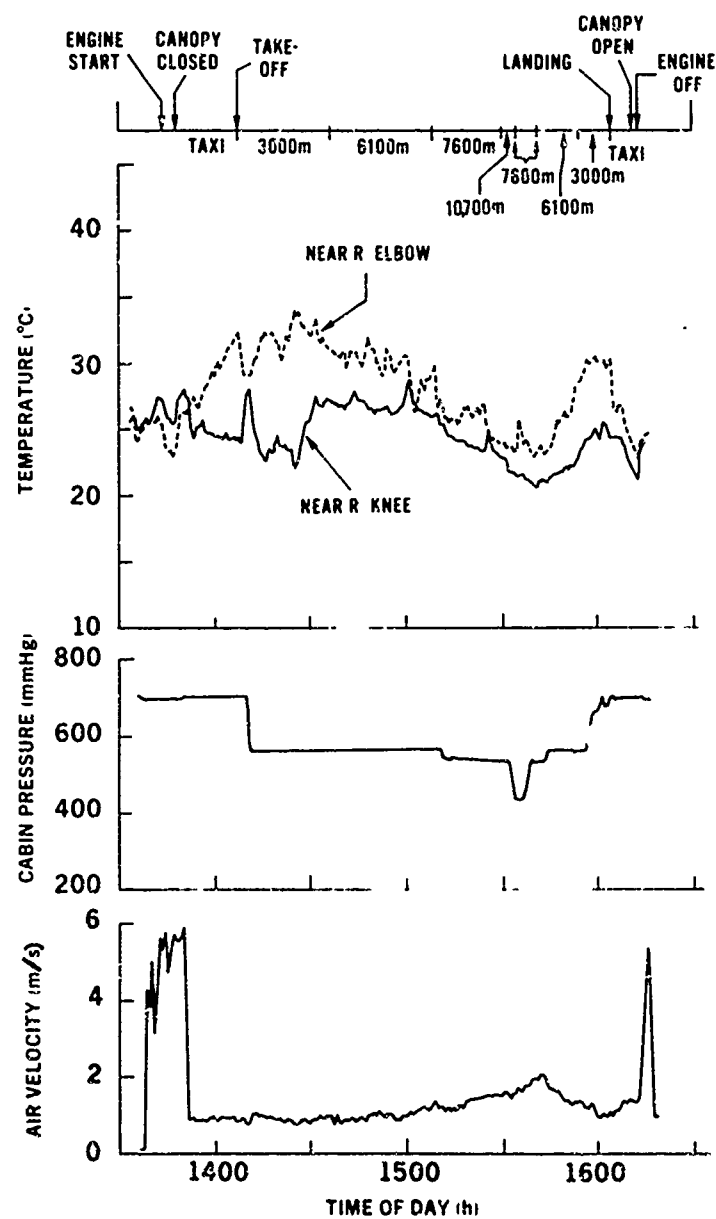
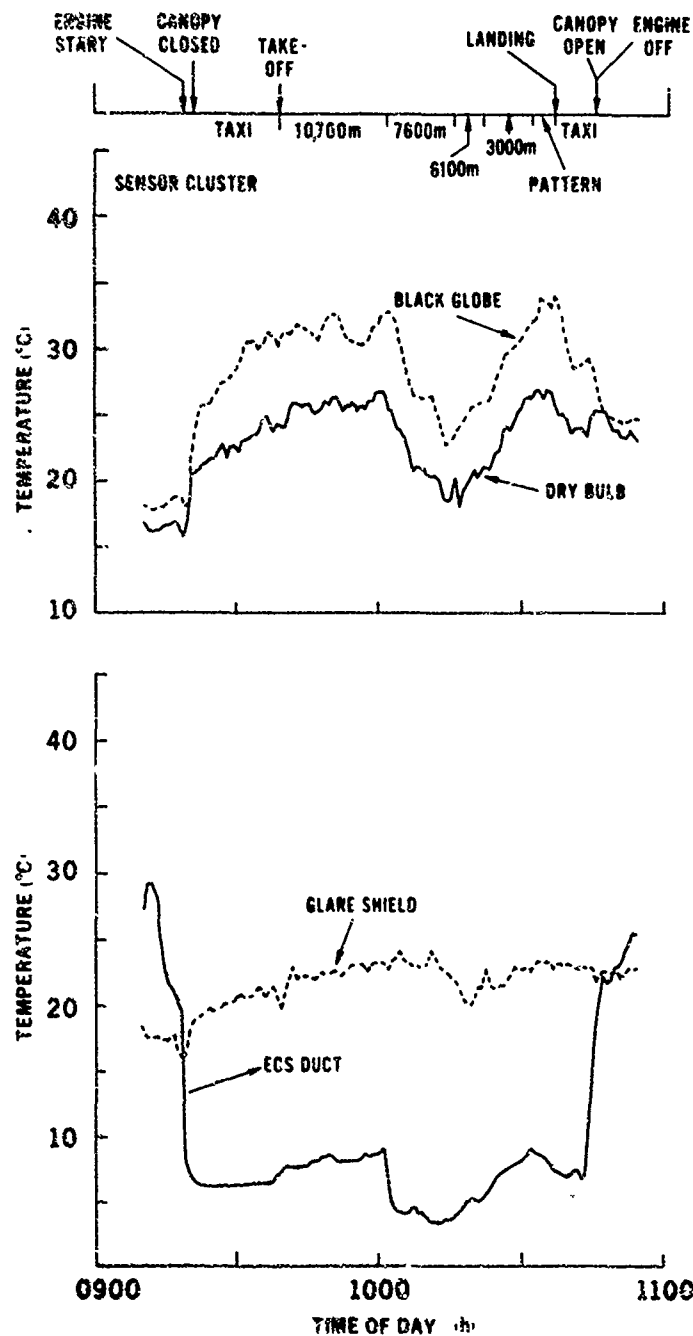


Figure B-17 (continued).



AIRFIELD CLIMATE CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ASR HUM [mmHg]	PRESSURE [mmHg]	CLOUD COVER
PRETEST:	19.1	5.6	40	6.6	761.3	CLEAR
POSTTEST:	17.8	5.6	44	6.8	761.3	CLEAR

Figure B-18. F-15, 21 Sep 77.

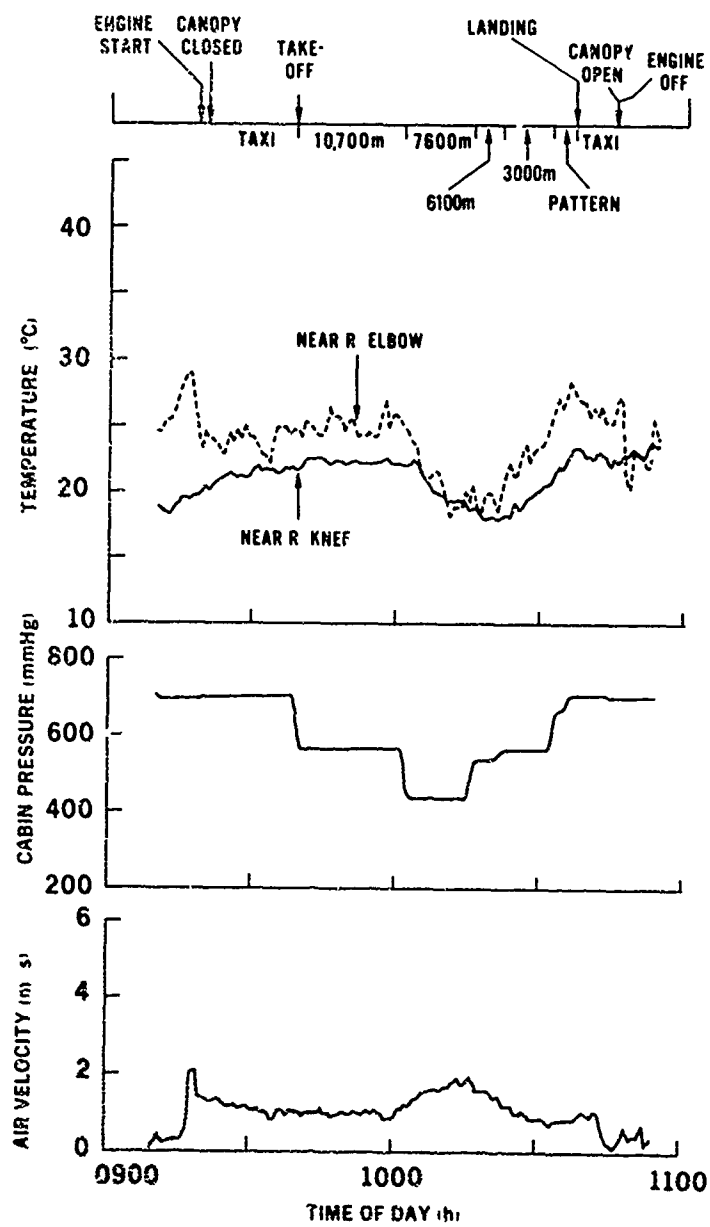
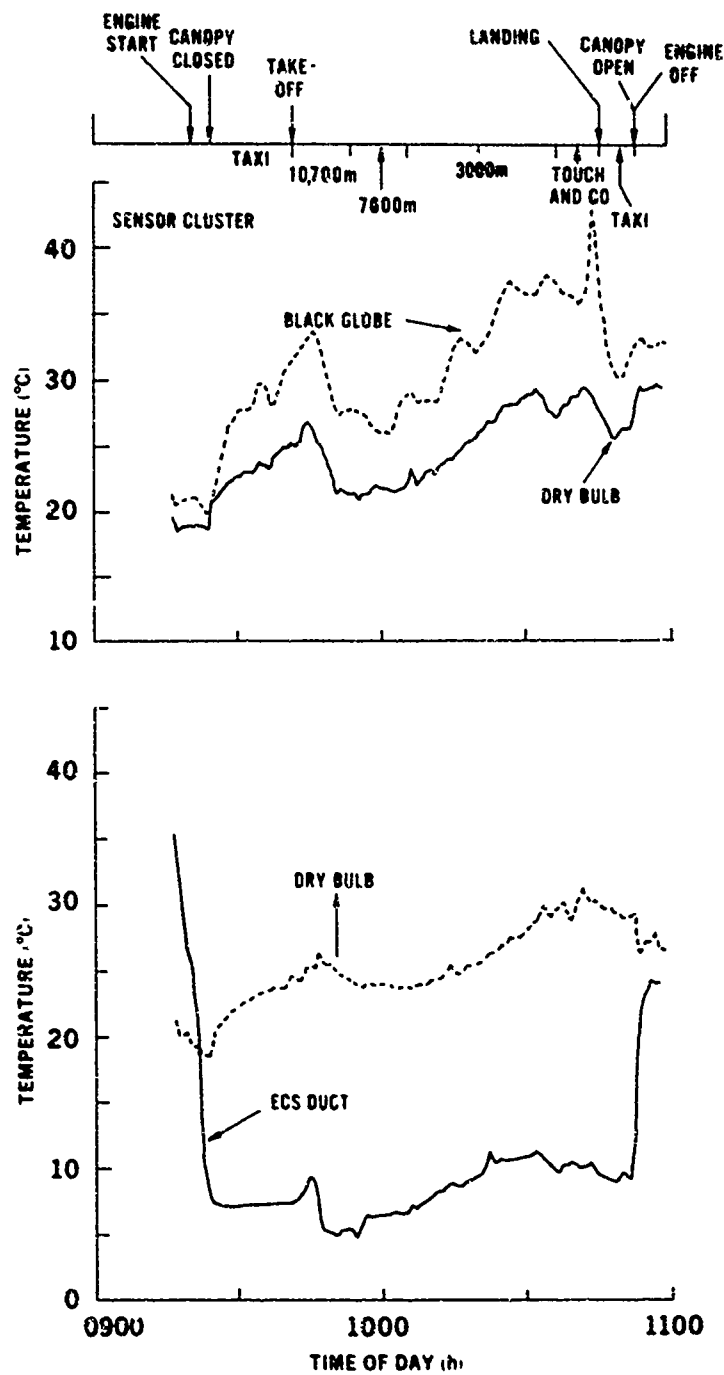


Figure B-18 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ABS HUM [mmHg]	PRESSURE [mmHg]	CLOUD COVER [mmHg]
PRETEST:	19.4	2.2	32	5.4	698.8	THIN, SCAT
POSTTEST:	21.1	1.7	22	5.2	698.8	THIN, SCAT
						50/2

Figure B-19. F-15, 23 Sep 77.

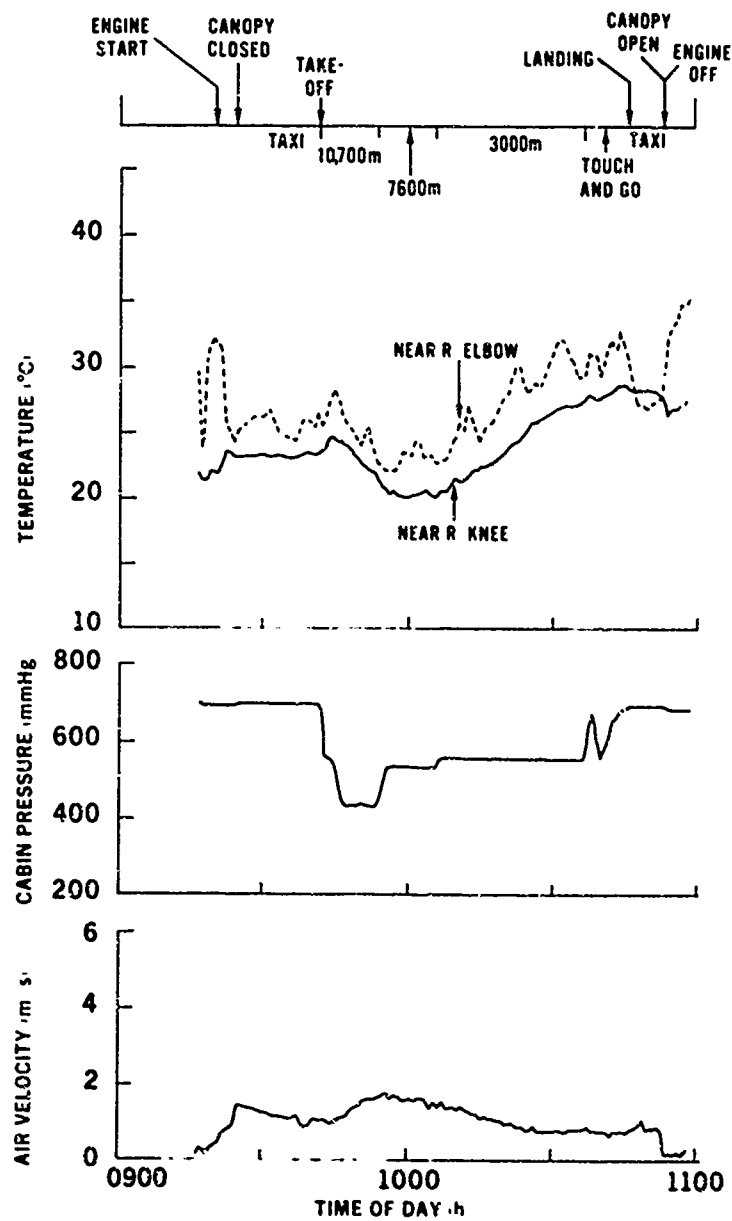


Figure B-19 (continued).

## TEST SUMMARY

Aircraft: YF-4E (#713)

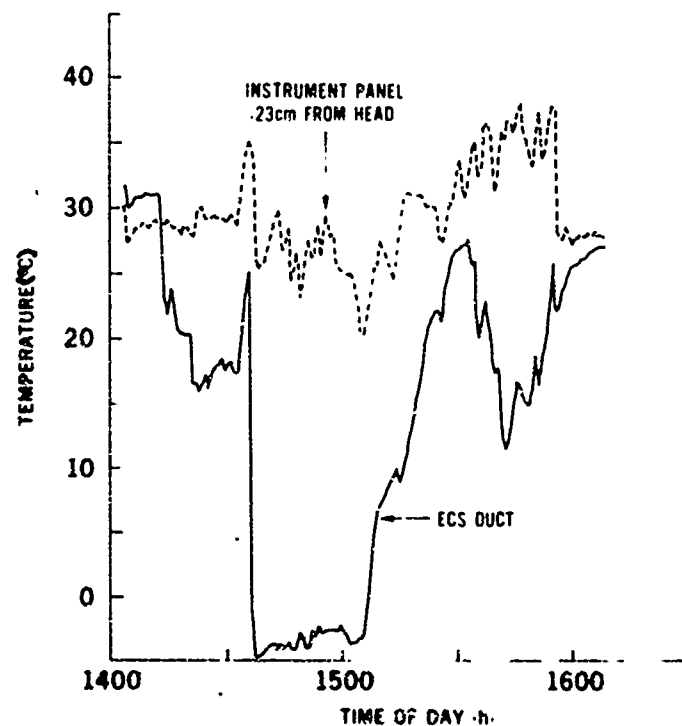
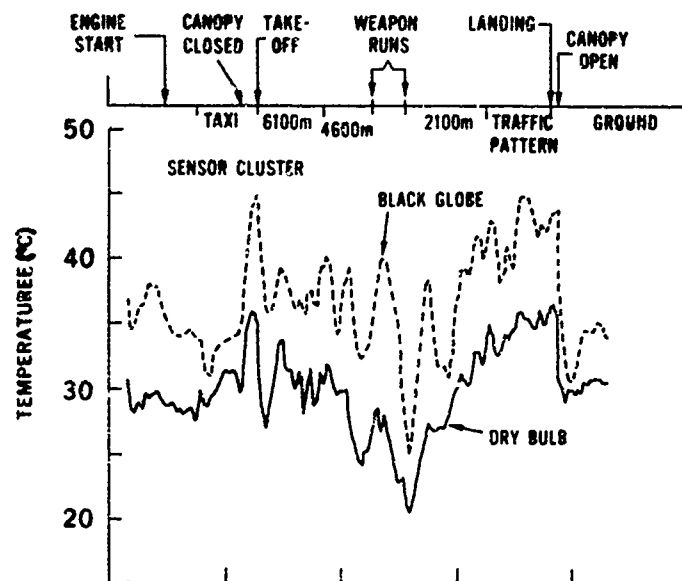
Dates: 27 Sep 77

Place: Edwards AFB CA

Sensor Cluster: Located on the right canopy rail, adjacent to and 15 cm lateral to the aircrew's right shoulders.

Additional Sensors: 1. Instrument panel at eye level, 30 cm from head.  
2. 15 cm from right elbow.  
3. 10 cm from right calf, in rudder well.  
4. Right-side ECS inlet duct.

PRECEDING PAGE BLANK-NOT FILMED



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER	WIND DIR/SPEED
PRETEST:	27.2	7.8	29	7.9	800.5	CLEAR	210/5
POSTTEST:	28.9	8.7	25	7.4	897.5	CLEAR	240/10

Figure B-20. YF-4E, 27 Sep 77.

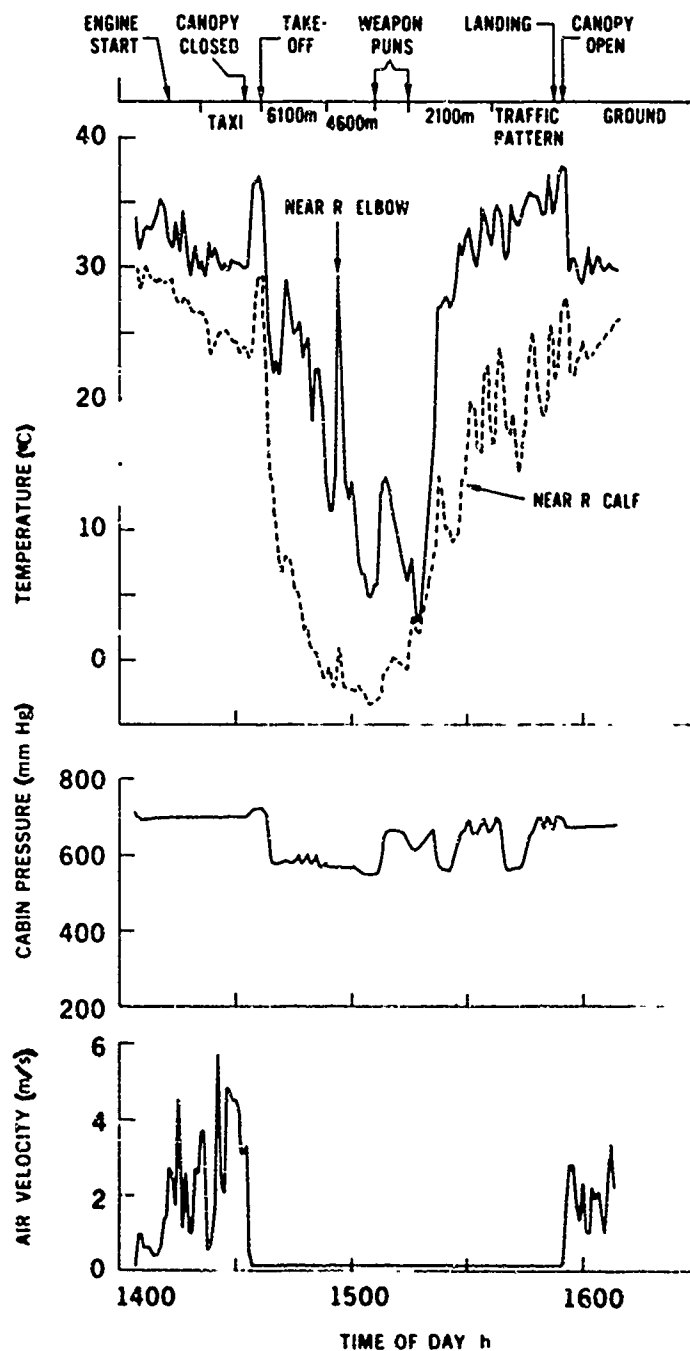


Figure B-20 (continued).

# TEST SUMMARY

Aircraft: YC-14 (#1874)

Dates: 2-4 Aug 77

Place: Edwards AFB CA

Sensor Cluster: 107 cm above flight deck, near left-window bulkhead.

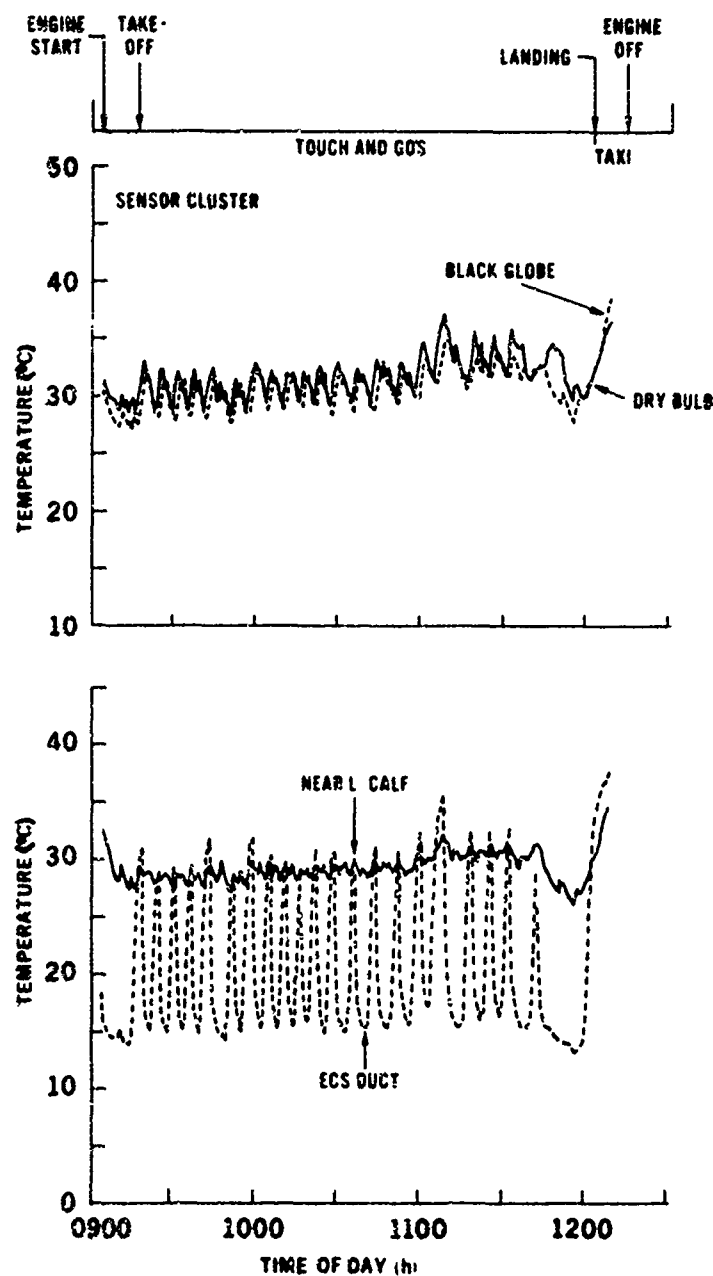
Additional sensors: 1. Left shoulder of pilot.

2. Right elbow of pilot, 43 cm above floor.

3. Right calf, 30 cm above floor.

4. ECS inlet duct.

PRECEDING PAGE BLANK-NOT FILLED



	AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB [°C]	DEW POINT [°C]	REL HUM [%]	ABS HUM [mmHg]	PRESSURE [mmHg]	CLOUD COVER	WIND DIR/SPEED
PRETEST:	29.4	8.3	21	8.21	700.5	700 M, SCAT	237/3
POSTTEST:	37.8	8.3	17	8.21	699.8	1030 M, SCAT	257/4

Figure B-21. YC-14, 2 Aug 77.

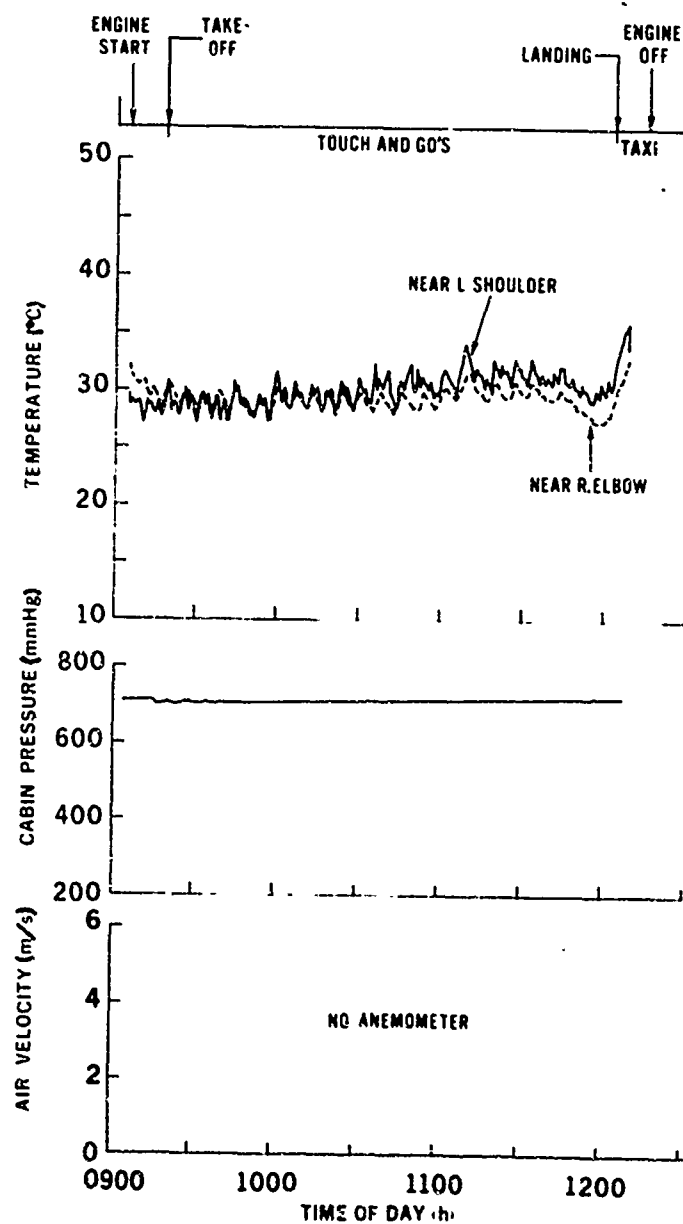
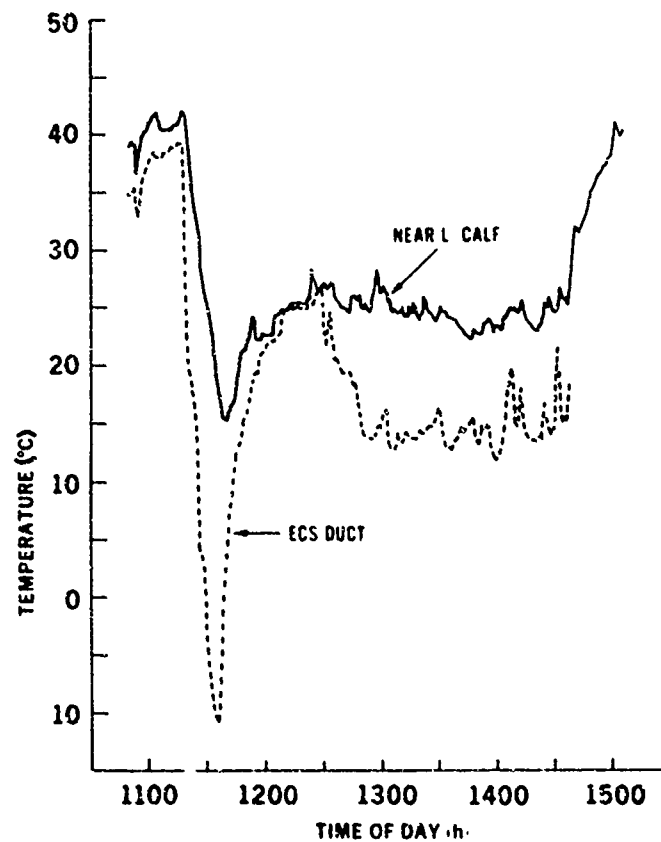
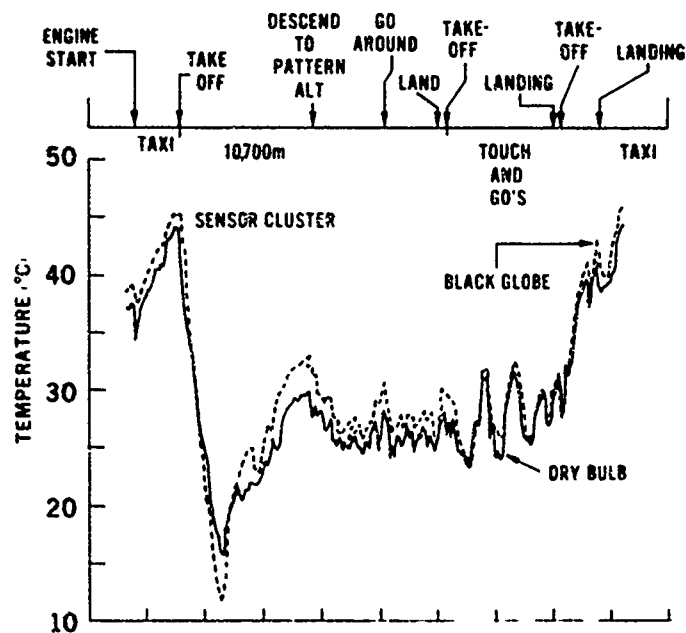


Figure B-21 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER
PRETEST:	35.8	8.3	19	8.21	699.5	550 M, SCAT
POSTTEST:	38.3	8.3	16	8.21	698.0	1830 M, SCAT
						WIND DIR/SPEED
						250/11
						230/11

Figure B-22. YC-14, 3 Aug 77.

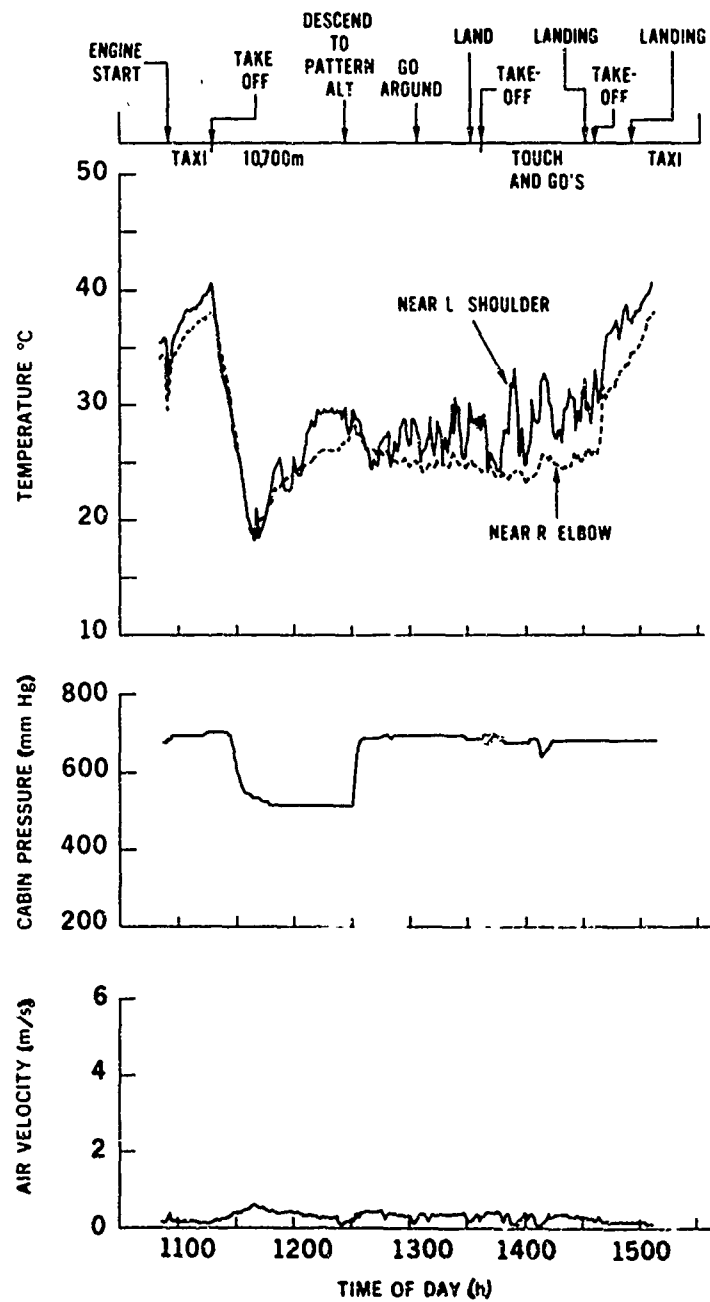
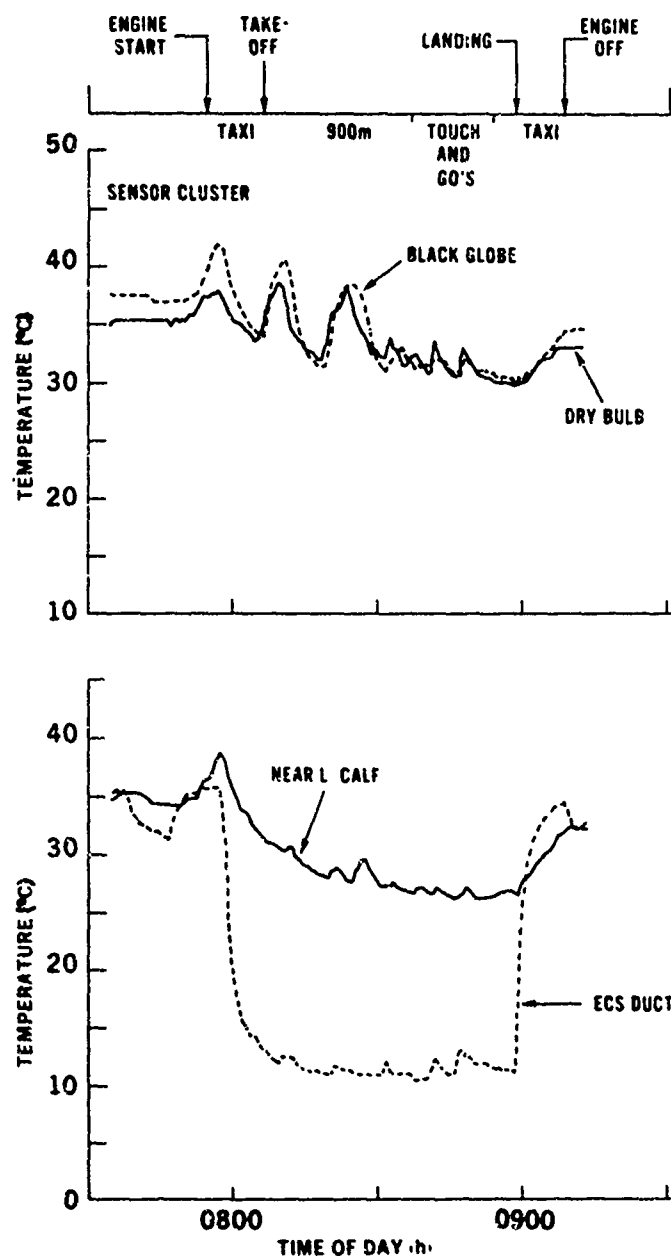


Figure B-22 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	CLOUD COVER WIND DIR/SPEED
PRETEST:	26.7	6.1	27	7.06	696.3	CLEAR 220/5
POSTTEST:	31.7	5.6	17	6.82	696.0	CLEAR 240/12

Figure B-23. YC-14, 4 Aug 77.

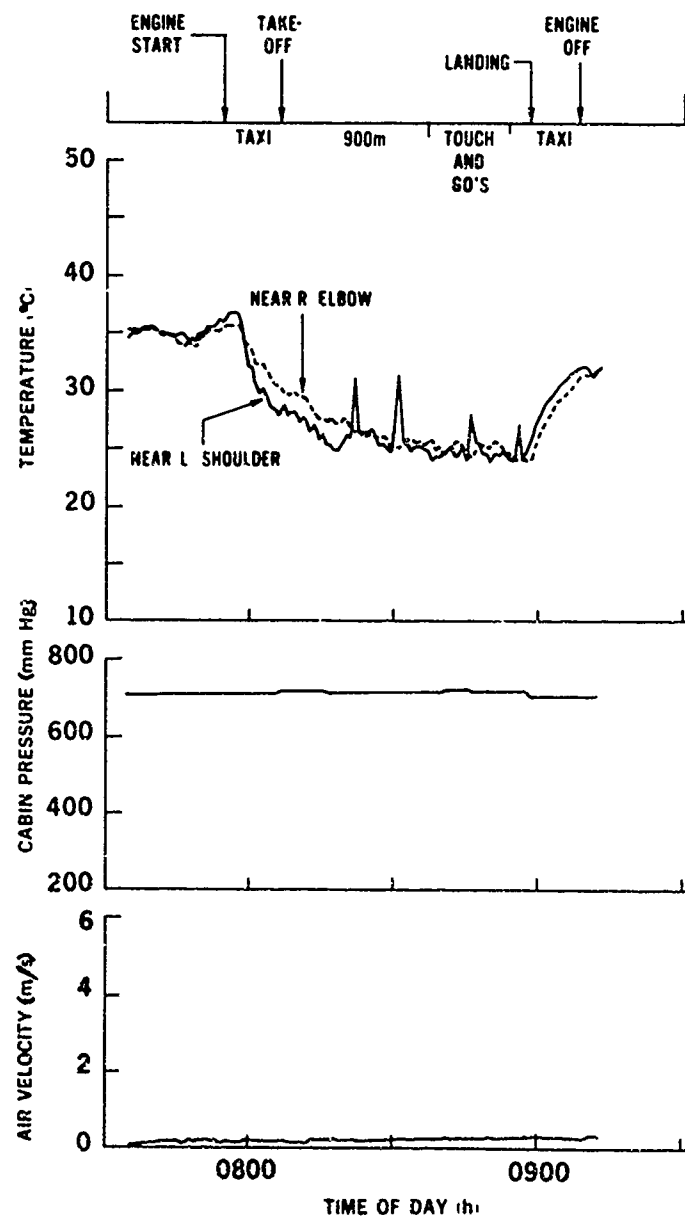
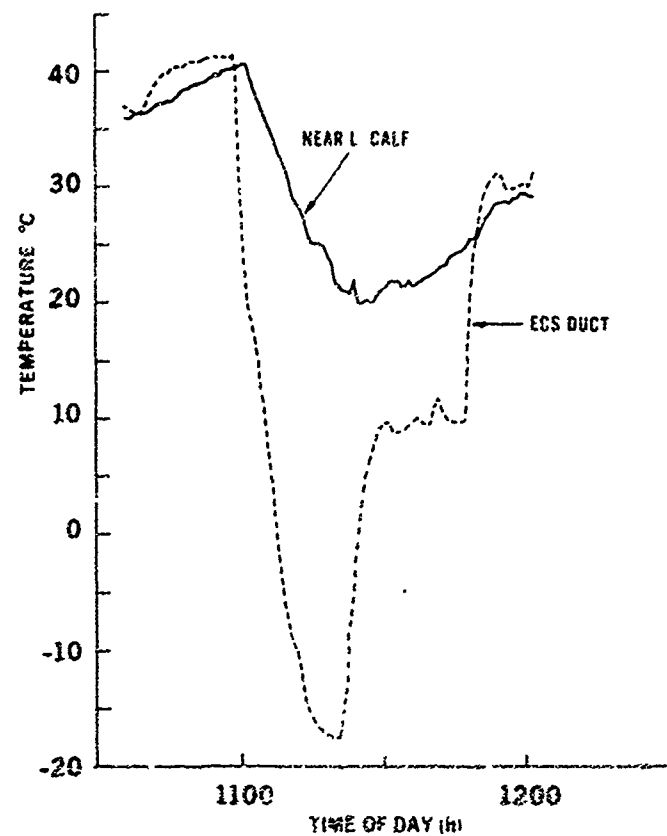
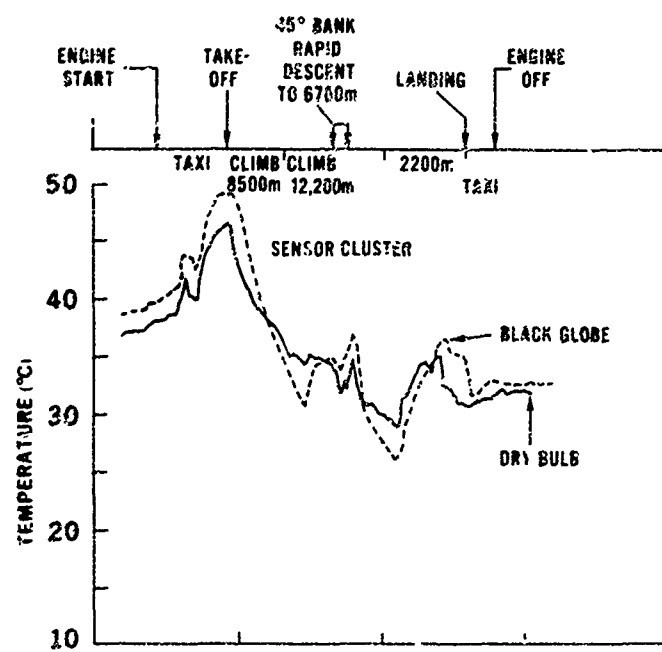


Figure B-23 (continued).



AIRFIELD CLIMATIC CONDITIONS						
	DRY BULB (°C)	DEW POINT (°C)	REL HUM (%)	ABS HUM (mmHg)	PRESSURE (mmHg)	WIND DIR/SPEED
PRETEST:	25.5	7.2	17	7.6	999.0	CLEAR 240/8
POSTTEST:	24.7	7.6	17	7.9	999.8	CLEAR 260/8

Figure B-24. YC-14, 4 Aug 77.

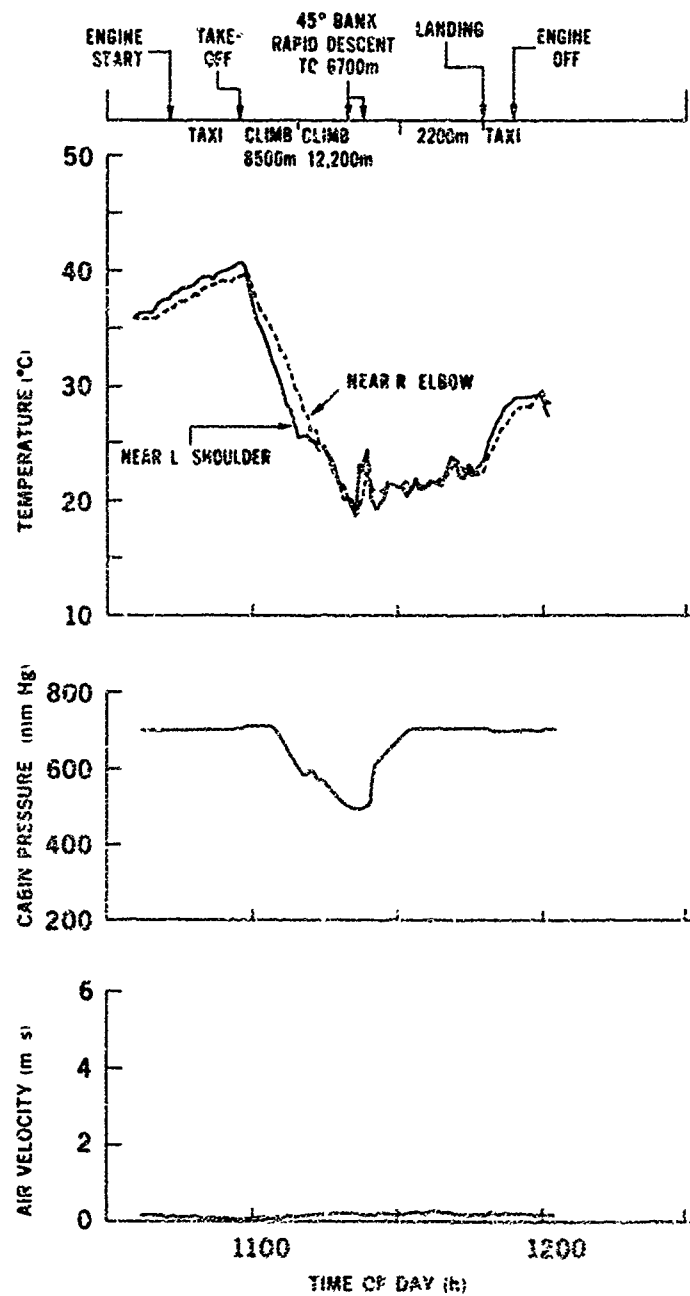


Figure B-24 (continued).

USAF SCHOOL OF AEROSPACE MEDICINE  
AEROSPACE MEDICAL DIVISION (AFSC)  
BROOKS AFB TX 78235

OFFICIAL BUSINESS  
PENALTY FOR PRIVATE USE, \$300